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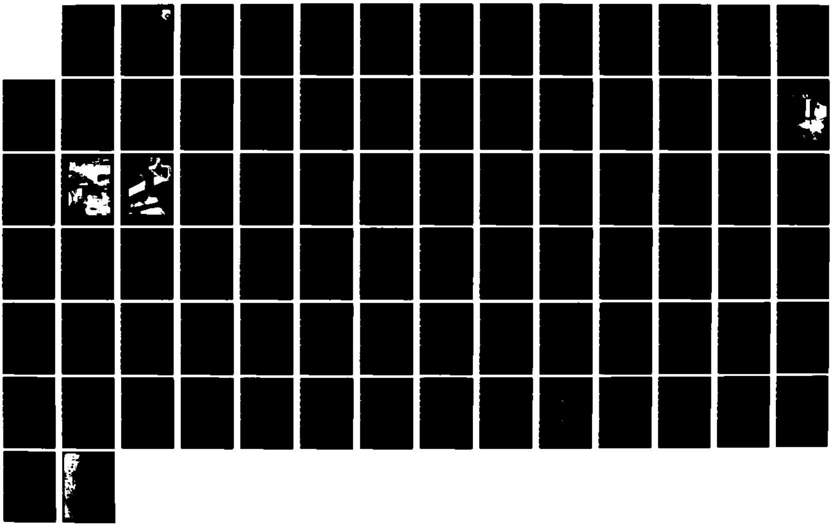

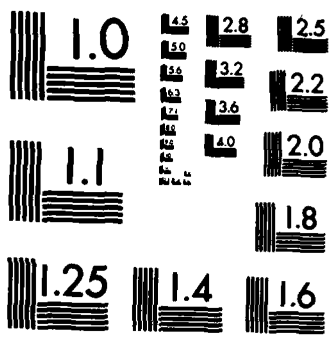
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AFWAL-TR-82-2121
Volume II

STRUCTURAL ELEMENT TESTING AND REAL BLADE IMPACT TESTING

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FINAL REPORT FOR PERIOD OCTOBER 1977 - JUNE 1980

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This technical report has been reviewed and is approved for publication.

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This report contains all of the unexpanded strain and strain rate results of an experimental program concerned with performing nonrotating bench impact tests on test specimens ranging from simple cantilevered beams and plates to real fan blades. This study was carried out under Task VI "Structural Element Tests" which is part of the overall program "Foreign Object Impact Damage Criteria."

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Three types of blade materials, geometries, and sizes were investigated using ice and substitute bird material as the impactors. The fan blades investigated were the J79 using 403 stainless steel material, the F101 blade using 8Al-1Mo-1V (8-1-1) titanium, and the APSI metal matrix blade material of boron/aluminum.

The simple elements, such as beams and plates, were impact tested with progressive introduction of airfoil geometric parameters to validate experimentally the analytical predictions of Tasks V and VIII of the overall program. General Electric Company was to conduct the Tasks V and VIII phases of the program. Impact tests were also conducted on actual fan blades to permit deriving a correlation between the structural element specimens and the full-scale blades.

The data collected from the impact tests included accurate impact conditions, dynamic displacement of the specimens at discreet points, strain/time histories local to the impact site and at critical blade stress regions identified from the structural response models, pre-test and post-test material properties, and damage assessment.

Because of the enormous amount of data (especially strain and strain rate plots versus time), the Task VI work is described in two reports (Volumes I and II). The Volume I report described in detail selected impacts where the strain data was expanded for the first several milliseconds. Volume I also gave the deflection data and photographs showing the damage specimens and actual blades. This report (Volume II) gives all of the unexpanded strain and strain rate data.

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SECTION 1
INTRODUCTION

Turbine blade damage resulting from the ingestion of foreign objects is a real threat to aircraft operation and an obstacle to the development of more efficient engines. Foreign objects range from large birds and ice to small hard particles such as sand. Impacts will almost always cause at least localized minor damage that may be corrected by maintenance procedures. Impact damage to blades may also be severe enough to cause catastrophic failure of an engine, resulting in immediate power loss, and jeopardizing the entire aircraft.

The threat is inevitably associated by the environment in which the engine is constrained to operate. Engine speed, blade material, blade geometry, point of impact, and type and size of the impactor all play important roles in determining the nature and severity of damage which might occur. The blade designer's task is to either design a blade which has a specified level of resistance to foreign object damage (FOD) or to evaluate a given blade and predict the extent of damage to be expected from a particular threat.

The FOD response of fan blades can be divided into two separate problem areas. One concerns the local blade damage and the second deals with the structural damage. Local damage occurs during the impact event and is confined to within several projectile diameters of the center of the impact site. Structural damage occurs at later times and at points which are, in general, well away from the impact site.

The overall design problem has two aspects. The first aspect is a ballistic impact problem. In this instance, a method must be developed to relate the mode and extent of damage to the threat and target parameters. The second aspect of the design problem is to relate the ballistic impact induced damage to the

residual properties of the blade. It is the degradation of the mechanical properties of the blade that is the most serious consequence of an FOD event.

This report contains all of the unexpanded strain and strain rate results of an experimental program concerned with perfroming nonrotating bench impact tests on test specimens ranging from simple contilevered beams and plates to real blades. This study was carried out under Task VI "Structural Element Tests" which is part of the overall program "Foreign Object Impact Damage Criteria". The simple elements, such as beams and plates, were to be tested with progressive introduction of airfoil geometric parameters to validate experimentally the analytical predictions of Tasks V and VIII of the overall program. The purpose of Task V is to derive parametric relationships describing the changes in dynamic structural response of impacted simple elements such as plates and beams with the progressive introduction of blade airfoil geometric features. The purpose of Task VIII is to derive criteria for predicting foreign object impact damage tolerance.

Because of the enormous amount of data (especially strain and strain rate plots versus time), the Task VI work is described in two reports (Volumes I and II). Volume I described in detail selected impacts where the strain data is expanded for the first several milliseconds. Volume I also gives the deflection data and photographs showing the damaged specimens and actual blades. Appendix B of this report contains all of the unexpanded strain and strain rate time histories. The strain and strain rate data in the form of plots versus time in Appendix B are originals which are attachments to the Volume II Report. The reason this approach was taken was because of the massive amount of data. It would be unreasonable to consider reproducing all of the data contained in Appendix B. A single copy of the original plots was delivered to A. F. Storace, MS H36, General Electric Company, Aircraft Engine Group, Evendale Plant, Evendale, Ohio 45215.

SECTION 2
EXPERIMENTAL PROGRAM

The experimental program involved conducting nonrotating bench impact tests on test specimens ranging from simple cantilevered beams and plates to real blades. The response of the test specimens to impacts of substitute birds or ice was determined in the testing. The simple elements, such as beams or plates, were tested with progressive introduction of airfoil geometric parameters to validate experimentally the analytical predictions of Tasks V and VIII and to derive a correlation between structural element specimens and full-scale blades. This report contains all of the unexpanded strain and strain rate results of the impact tests in Appendix B.

Three types of blade materials, geometries, and sizes were investigated using ice and substitute bird materials as the impactors. The impactors were gun launched to impact the leading edge of the test specimens in the majority of the testing.

2.1 STUDY OBJECTIVES AND APPROACH

The overall objective of this study was to experimentally determine the response (both local and structural) of the various blade materials investigated. The data collected from the impact tests included accurate impact conditions, dynamic displacement of the specimens at discreet points, strain/time histories local to the impact site and at critical blade stress regions identified from the structural repsonse models, pre-test and post-test material properties, and damage assessment. The simple elements were tested with progressive introduction of airfoil geometric parameters to validate experimentally the analytical predictions of Tasks V and VIII. Impact tests were also conducted on real blades to derive a correlation between structural element specimens and full-scale blades.

The three blade types investigated in the study were the J79 blade using 403 stainless steel; the F101 blade using 8Al-1MO-IV (8-1-1) titanium; and the APSI metal matrix boron/aluminum blade. The geometries of the test specimens were similar to the geometries at the 50 percent span location of the three blade types investigated. For example, the material, leading edge thickness, trailing edge thickness, taper angle, specimen thickness, width, and span length of the test specimens were identical to that of the actual blades at the 50 percent span location.

A baseline series of tests was conducted on the titanium material, a supplementary series was conducted on the stainless steel material, and a more complete series was conducted on the advanced composite material. Titanium was chosen as the baseline material as it is the most common current blade material. Stainless steel, being a metal, was anticipated to behave basically similar to titanium and would not require such a complete investigation. The composite material was expected to behave significantly different from the metals and a more thorough investigation would be required.

As indicated earlier, the titanium material was used as the baseline material. The test conditions of the impact tests conducted on the titanium material are summarized in Table 1. This baseline series of impact tests considered all impact conditions and blade geometrical effects were introduced progressively (not independently) except camber and twist. It was established early in the study that camber and twist would be very expensive to incorporate on titanium; therefore, camber and twist would be investigated utilizing stainless steel and the composite specimens. The impact tests for all the materials were conducted at ambient temperature conditions.

The supplementary series of impact tests on 403 stainless steel specimens is summarized in Table 2. The basic behavior of stainless steel was assumed to be similar to that of the titanium

TABLE 1. BASELINE TEST CONDITIONS FOR TITANIUM SPECIMENS

Impact Parameters	Mass (85 g and 680 g birds, 50.8 mm ice balls)	(3)
	Impact Velocity (no damage, threshold damage, severe damage)	(3)
	Location/Angle (70% span/ Center-normal; Edge-oblique)	(2)
	(30% span/Center-normal; Edge-oblique)	(2)
Blade Geometry Parameters	Aspect Ratio (1/2 blade-like, blade-like)	(2)
	Thickness/Chord Ratio (1/2 blade-like, blade-like)	(2)
	Shape (constant thickness, airfoil, blade-like)	(3)
	Shrouds (none, blade-like)	(2)

TABLE 2. IMPACT TESTS FOR STAINLESS STEEL SPECIMENS

Impact Parameters	Mass (680 g birds)	(1)
	Impact velocity (no damage, threshold damage, severe damage)	(3)
	Location Angle (70% span/ edge-oblique)	(1)
Blade Geometry Parameters	Aspect Ratio (blade-like)	(1)
	Shape (constant thickness)	
	Camber	(1)
	Twist	(1)

material. Ice impactors were also considered not to be an important threat on the stainless steel specimens, therefore ice impacts were not considered. As indicated earlier, the camber and twist blade parameters were investigated using the stainless steel specimens. The camber and twist blade parameters were introduced progressively (not independently). In addition, flat specimens with a blade-like aspect ratio were also investigated in regards to their response to oblique bird impacts. Only 680 g (1.5 pound) substitute bird impacts were considered in the impact testing of the stainless steel specimens. All the impacts were conducted at the 70 percent span location with the impacts being oblique leading edge impacts.

The boron/aluminum composite material specimen series of impact tests is outlined in Table 3. The composite material was considered to behave quite differently from the metals; therefore, all the impact conditions were given consideration. The only projectile considered was the 85 g (3 ounce) substitute bird. All of the impacts were leading edge oblique impacts at the 70 percent span location on the specimens. The blade parameters investigated included the aspect ratio, thickness to chord ratio, shape, camber, and twist. Again, as for the titanium material, the blade geometrical effects were introduced progressively (not independently).

The testing is organized into groups. The test matrix for the impacts on the various material specimen groups is described in Table 4. The table describes the structural elements, element fixity and material, the loading and impactor, and the impact location and angle. Details of the shape, size and configuration of the structural elements are provided in Table 5. The structural elements are discussed in greater detail in the Volume I report describing the results of the testing.

In addition to impact testing of beam and plate-like test specimens, a number of impact tests were also conducted on full

TABLE 3. TEST CONDITIONS FOR BORON/ALUMINUM COMPOSITE SPECIMENS

Impact Parameters	Mass (85 g bird) Impact Velocity (no damage, threshold damage, severe damage) Location Angle (70% span/edge-oblique)
Blade Geometry Parameters	Aspect Ratio (1/2 blade-like, blade-like) Thickness/Chord Ratio (1/2 blade-like, blade-like) Shape (constant thickness, blade-like Camber Twist

scale component blades. This impact testing of the actual blades was coordinated with the full scale blade testing of Task IVA where the impact tests were conducted to establish the strain rate limits for the material property tests of Task IVA. The results of this testing was described in the Volume I report. The test matrix for the Task IVA and Task VI work is outlined in Table 6. The Task IVA blade testing was to establish the strain rate limits of the blades; therefore, the impact velocities to be used in these impact tests corresponded to those which would be typical of an impact at 70 percent span and 30 percent span levels at full power settings of the engine during takeoff for each of the blade types. Impacts at the 70 percent span level are representative of the highest velocity impacts experienced by a blade. Impacts at the 30 percent percent span level are typical of those in the highest stress regions of the blade where it is most vulnerable to the effects of impact degradation. In the case for the Task VI blade

TABLE 4. PARAMETRIC MATRIX DEFINING STRUCTURAL ELEMENTS AND IMPACTS CONDITIONS

Group Number	Structural Element and Comments	Impactor	Impact Location	Impact Incidence	Shroud Restraint	Specimen Material
1	Flat Plate with Blade-Type Aspect Ratio	85 g (3 ounce) Bird	Center Impact @ 70% Span	Normal	No	Ti 8-1-1
2	Same as Group 1	50.8 mm (2 inch) Ice Ball	Edge Impact @ 30% Span	Oblique	No	Ti 8-1-1
3	Same as Group 1	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Ti 8-1-1
4	Flat Plate with One-Half Blade-Type Aspect Ratio	85 g (3 ounce) Bird	Center Impact @ 70% Span	Normal	No	Ti 8-1-1
5	Same as Group 4	680 g (1.5 lb) Bird	Edge Impact @ 30% Span	Oblique	No	Ti 8-1-1
6	Flat Plate with Blade-Type Aspect Ratio and One-Half Blade-Type Thickness/Chord Ratio	85 g (3 ounce) Bird	Center Impact @ 70% Span	Normal	No	Ti 8-1-1
7	Plate with Blade-Type Aspect Ratio and Airfoil (Tapered Cross Section)	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Ti 8-1-1
8	Same as Group 7	680 g (1.5 lb) Bird	Edge Impact @ 70% Span	Oblique	No	Ti 8-1-1
9	Plate with Blade-Type Aspect Ratio and Bladelike Cross Section	680 g (1.5 lb) Bird	Edge Impact @ 70% Span	Oblique	No	Ti 8-1-1
10	Same as Group 9	85 g (3 ounce) Bird	Center Impact @ 70% Span	Normal	Yes	Ti 8-1-1
11	Flat Plate with Blade-Type Aspect Ratio	680 g (1.5 lb) Bird	Edge Impact @ 70% Span	Oblique	No	403 Stainless Steel
12	Cambered Flat Plate with Blade-Type Aspect Plate	680g (1.5 lb) Bird	Edge Impact @ 70% Span	Oblique	No	403 Stainless Steel
13	Cambered Twisted Flat Plate with Blade-Type Aspect Ratio	680 g (1.5 lb) Bird	Edge Impact @ 70% Span	Oblique	No	403 Stainless Steel
14	Cross Ply Flat Panel with Blade-Type Aspect Ratio	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/Aluminum
15	Cross Ply Flat Panel with One-Half Blade-Type Aspect Ratio	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/Aluminum
16	Cross Ply Flat Panel with Blade-Type Aspect Ratio and One-Half Blade-Type Thickness to Chord Ratio	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/Aluminum
17	Cross Ply Panel with Blade-Type Aspect Ratio and Bladelike Cross Section	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/Aluminum
18	Cross Ply Flat Panel with Blade-Type Aspect Ratio and Camber	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/Aluminum
19	Cross Ply Flat Panel with Blade-Type Aspect Ratio with Camber and Twist	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/Aluminum

TABLE 5. SHAPE, SIZE, AND CONFIGURATION DETAILS OF STRUCTURAL ELEMENTS

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<tr><th>Groups</th><th>Specimen Span Length (mm)</th><th>Specimen Cross Section</th><th>Specimen Material</th></tr>
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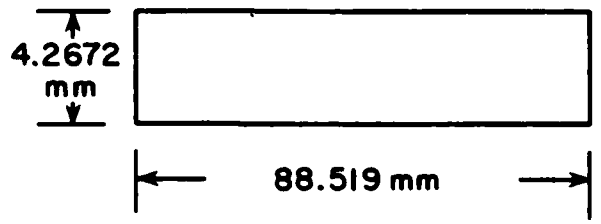
155.575</td><td>Specimen Cross Section #1

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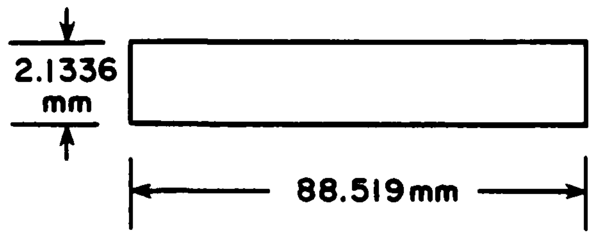

</td><td>Ti 8-1-1</td></tr>
<tr><td>7-8</td><td>311.150</td><td>Specimen Cross Section #3

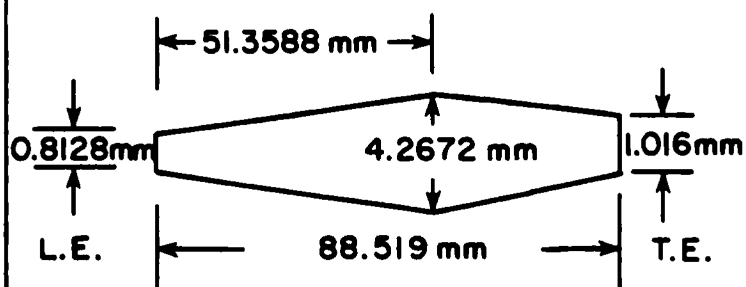
</td><td>Ti 8-1-1</td></tr>
<tr><td>9-10</td><td>311.150</td><td>Specimen Cross Section #4

</td><td>Ti 8-1-1</td></tr>
</table>

TABLE 5. SHAPE, SIZE, AND CONFIGURATION DETAILS OF STRUCTURAL ELEMENTS (Continued)

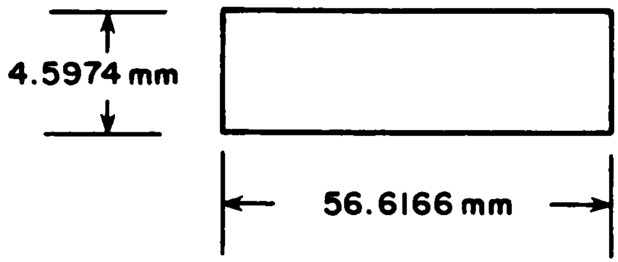
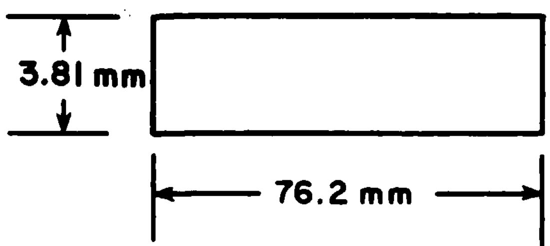
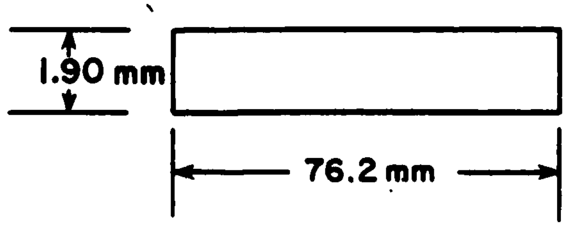
Groups	Specimen Span Length (mm)	Specimen Cross Section	Specimen Material
11	245.872	Specimen Cross Section #5 	403 Stainless Steel
12	245.872	Specimen Cross Section #6 Same as specimen Cross Section #5, but with Camber with Radius of Curvature of 27.7 cm.	403 Stainless Steel
13	245.872	Specimen Cross Section #7 Same as specimen Cross Section #6, but with twist of 49° through free span	403 Stainless Steel
14 15	154.940 77.470	Specimen Cross Section #8 Cross Ply Layup (0°/22°/0°/-22°) 	B/Al
16	154.940	Specimen Cross Section #9 Cross Ply Layup (0°/22°/0°/-22°) 	B/Al

TABLE 5. SHAPE, SIZE, AND CONFIGURATION DETAILS OF STRUCTURAL ELEMENTS (Continued)

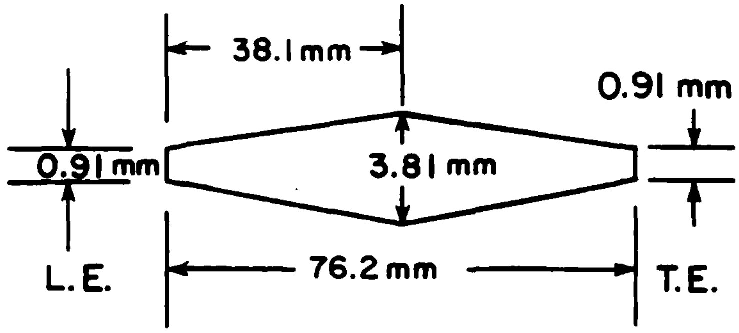
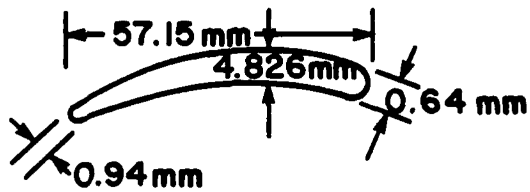
Groups	Specimen Span Length (mm)	Specimen Cross Section	Specimen Material
17	101.600	Specimen Cross Section #10 Cross Ply Layup (0°/22°/0°/-22°) with blade-like cross section  	B/Al
18	154.940	Specimen Cross Section #11 Constant Chord Airfoil Shape Cross Ply Layup (0°/22°/0°/-22°) with Camber of Radius of Curvature of 101.6 mm (4.0 inches).  	B/Al
19	154.940	Specimen Cross Section #12 Same as Specimen Cross Section #11, but with twist of approximately 3.0°.	B/Al

TABLE 6. MATRIX AND TEST CONDITIONS FOR ACTUAL BLADE IMPACTS

Group Number	Blade Type and Comments	Purpose of Test	Impactor	Impact Location	Impact Incidence	Shroud Restraint	Specimen Material
1B	F101	Determine Strain Rates	85g (3 ounce) Bird	Edge Impact @ 30% Span	Oblique	Yes	Ti 8-1-1
2B	F101	Determine Strain Rates	85g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	Yes	Ti 8-1-1
3B	F101	Determine Strain Rates	680g (1.5 lb.) Bird	Edge Impact @ 30% Span	Oblique	Yes	Ti 8-1-1
4B	F101	Determine Strain Rates	680g (1.5 lb.) Bird	Edge Impact @ 70% Span	Oblique	Yes	Ti 8-1-1
5B	F101	Analysis	Slab Ice	Edge Impact @ 70% Span	Oblique	Yes	Ti 8-1-1
6B	J79	Determine Strain Rates	85g (3 ounce) Bird	Edge Impact @ 30% Span	Oblique	No	403 Stainless Steel
7B	J79	Determine Strain Rates	85g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	403 Stainless Steel
8B	J79	Determine Strain Rates	680g (1.5 lb.) Bird	Edge Impact @ 30% Span	Oblique	No	403 Stainless Steel
9B	J79	Determine Strain Rates and Analysis	680G (1.5 lb.) Bird	Edge Impact @ 70% Span	Oblique	No	403 Stainless Steel
10B	J79	Analysis	50.8 mm (2 inch) Ice Ball	Edge Impact @ 30% Span	Oblique	No	403 Stainless Steel
11B	J79	Analysis	Slab Ice	Edge Impact @ 30% Span	Oblique	No	403 Stainless Steel
12B	APSI	Determine Strain Rates	85g (3 ounce) Bird	Edge Impact @ 30% Span	Oblique	No	Boron/ Aluminum
13B	APSI	Determine Strain Rates and Analysis	85 g (3 ounce) Bird	Edge Impact @ 70% Span	Oblique	No	Boron/ Aluminum
14B	APSI	Analysis	50.8 mm (2 inch) Ice Ball	Edge Impact @ 30% Span	Oblique	No	Boron/ Aluminum
15B	APSI	Analysis	Slab Ice	Edge Impact @ 30% Span	Oblique	No	Boron/ Aluminum

impacts, the impact velocity was varied to obtain no damage, threshold damage, and severe damage of the blade. The impact angles on the various test specimen and actual blade impacts were to correspond to the impact angles that would occur on the actual blades for a given span location. These impact angles, impact velocities, and bird mass values were determined from the blade geometry, the blade velocity for a given span location, and the aircraft speed.

2.1.1 Specimen Materials and Geometries

As indicated earlier, the three blade types to be investigated were the F101 blade using 8-1-1 titanium, the J79 blade using 403 stainless steel, and the APSI blade using boron/aluminum material. These choices correspond to those which would be investigated, analytically and experimentally in other tasks of the overall program. The geometries of the test specimens used in the study were similar to the geometries of the actual blades at the 50 percent span location. The material, leading edge and trailing edge thickness, overall thickness, taper angle, chord width, and span length values of the test specimens were identical to that of the various blade types.

2.1.1.1 F101 Test Specimens

The test specimens simulating the F101 blade were fabricated from 8-1-1 titanium material. The leading edge thickness for the plate specimens with a blade-type aspect ratio and an airfoil (tapered cross section) shape was 0.813 mm (0.032 inches). The trailing edge thickness was 1.016 mm (0.040 inches) and the maximum thickness was 4.267 mm (0.168 inches). The chord width was 88.519 mm (3.485 inches) and the span length was 311.150 mm (12.250 inches). All of the titanium specimens were in the shot peened condition to an intensity of 0.005 - 0.008 N using glass beads 0.58 - 0.84 mm (0.023 - 0.033 inch) diameter.

2.1.1.2 J79 Test Specimens

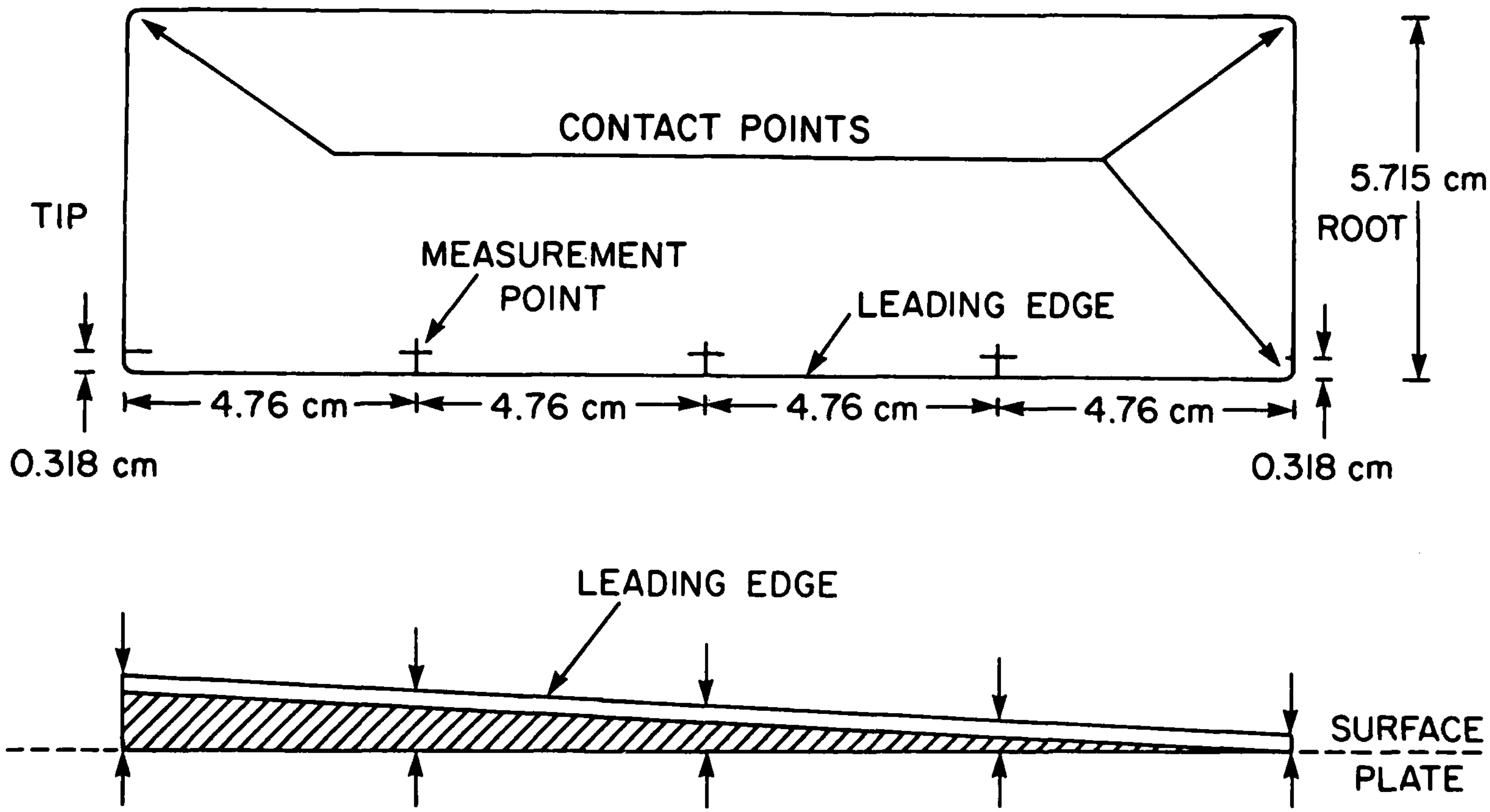
The test specimens simulating the J79 blade were fabricated of 403 stainless steel material. The maximum thickness of the blade-type aspect ratio specimens were 4.5974 mm (0.181 inches) and the chord width was 56.617 mm (2.229 inches). The span length for the specimens was 245.872 mm (9.680 inches). The camber for the J79 specimens had a radius of curvature of 276.900 mm (10.9 inches). The twist angle for the J79 specimens was 49 degrees from the root to the leading edge tip of the specimens.

2.1.1.3 APSI Test Specimens

Test specimens of boron/aluminum material simulating the APSI blade were fabricated by the General Electric Company. The leading edge thickness for the airfoil cross section specimens was 0.559 mm (0.022 inches) and the maximum thickness was 3.937 mm (0.155 inches). The specimens were symmetrical in shape. The chord width was 76.2 mm (3.0 inches) and the span length was 154.940 mm (6.1 inches). The cambered panels were fabricated using a J79 specimen die. The radius of curvature for the cambered specimens was about 101.6 mm (4.0 inches). The test angle for the twisted panels was approximately 3.0 degrees from the root to the leading edge tip of the specimens. The specimens had a stainless steel wire mesh outer ply. The symmetrical layup used in the specimens was 0°/22°/0°/-22° with the number of plies being sufficient to obtain the desired thickness. Measurements of the twist of the boron/aluminum specimens with camber and twist (Group 19 specimens of Tables 4 and 5) were determined before the impact for each specimen. Figure 1 shows how these twist measurements were conducted while Table 7 gives the measurements for each specimen.

2.1.2 Impactors

The substitute birds used instead of real birds were 85 g (3-ounce) and 680 g (1.5-pound) sizes. The



MEASUREMENT POINTS FOR CALCULATING TWIST OF COMPOSITE SPECIMENS.
TASK VI CONSTANT CHORD AIRFOIL-TYPE 2 (TWISTED).

Figure 1. Method Used tc Determine Twist for Each Group 19 Boron/Aluminum Specimen.

TABLE 7. PREIMPACT TWIST MEASUREMENTS FOR GROUP 19 BORON/ ALUMINUM STRUCTURAL ELEMENT SPECIMENS

Specimen No.	Root (mm)	#1 (mm)	#2 (mm)	#3 (mm)	Tip (mm)
VI AF-13	2.311	4.496	6.731	8.839	10.795
VI AF-14	2.261	4.064	6.147	8.052	9.728
VI AF-15	2.286	4.318	5.994	7.696	9.271
VI AF-16	2.413	4.242	6.248	8.230	9.906
VI AF-17	2.235	4.445	6.477	8.382	10.058
VI AF-18	2.413	4.318	6.147	7.747	9.348
VI AF-19	2.489	4.166	5.766	7.239	8.560
VI AF-20	2.311	3.962	5.207	6.858	8.484
VI AF-21	2.261	4.343	6.426	8.331	10.160
VI AF-22	2.388	4.369	6.223	7.798	9.423
VI AF-24	2.362	5.080	7.696	10.211	12.548
VI AF-25	2.438	4.826	7.137	9.474	11.430

85 g (3-ounce) bird was used to simulate a starling size bird while the 680 g (1.5-pound) bird was used to simulate a seagull sized bird. The artificial birds were cylindrical in shape with a length to diameter ratio of two. The artificial bird material was a mixture of microballoons and gelatin to obtain a porosity of 10 to 15 percent. The small bird had a diameter of 38.1 mm (1.5 inches) while the larger bird had a diameter of 76.2 mm (3.0 inches).

The mass of the 50.8 mm (2 inch) ice balls was approximately 65 g. These ice balls were molded using demineralized water. The slab ice was molded to a shape of a cylinder having a diameter of 73.0 mm (2.875 inches) and a length of 203.2 mm (8.0 inches). The mass of the slab ice in the impacts varied from 687 to 867 g dependeing on the final diameter and length values.

2.2 EXPERIMENTAL SETUP AND PROCEDURES

The impact tests were conducted on the large compressed gas gun range. The range configuration is capable of launching 25.4 to 76.2 mm (1.0 to 3.0 inch) diameter spheres or cylinders up to velocities of 350 m/s (1150 ft/s) using air as the gas medium. Higher velocities can be obtained using helium as the gas medium in the gun. A brief description of the range setup is given below.

2.2.1 Large Bore Compressed Gas Gun Range

Early in the study, the range setup for the artificial bird impacts were conducted on an 89 mm (3.5 inch) diameter smooth-bore gas gun having a launch length of 6.1 m (20.0 ft) and a sabot stopper section having a length of 2.9 m (9.5 ft). The projectile was launched in a standard one-piece balsa wood sabot with a cylindrical pocket. The size of the pocket in the sabot depended on the bird size to be fired. After launch, the gas pressure was released through slots in the sabot stopper tube and the sabot was stopped in the stopper section. The projectile would free-flight to the target over a distance of about 1.8 m (6.0 ft). A preslicer was used in conjunction with the launch system to slice a portion of the bird or ice projectile prior to impact such that only the center portion of the impactor diameter would actually load the target specimen since the majority of the impacts were leading edge hits. The preslicer shown in Figure 2 was not used for the normal chord center impacts on the flat plate or beam impacts. In the leading edge impacts, the specimens were positioned such that slicing would occur; thus, only the center portion of the projectile would load the target specimen.

The normal center impacts on the cantilevered flat plates were conducted using a 51 mm (2.0 inch) diameter smooth bore gun having a length of 7.9 m (26.0 ft). This particular gun setup was utilized without a sabot stopper section or a preslicer. In this case, the impactors were again launched

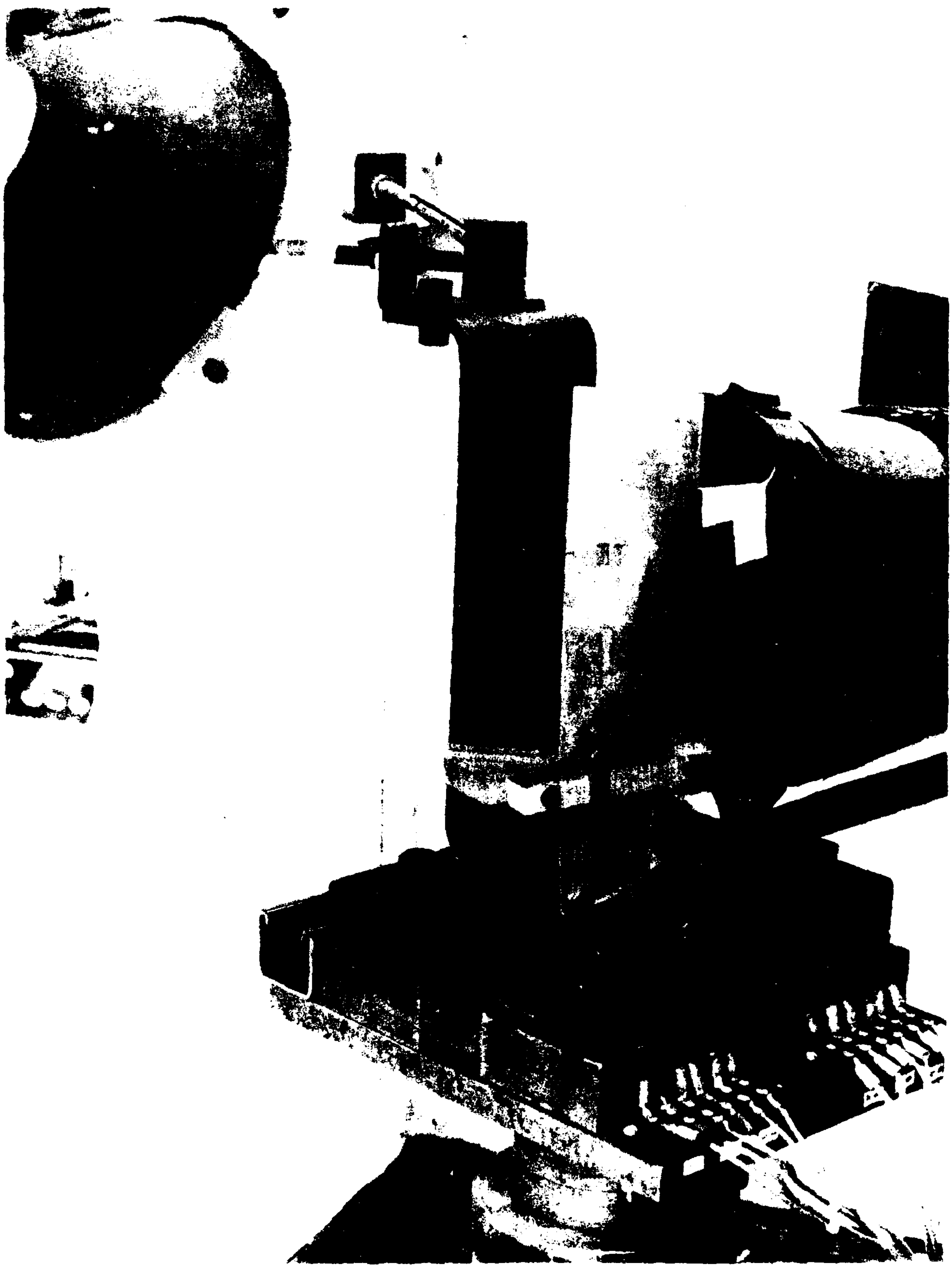


Figure 2. Photograph Showing Preslicer Utilized.

in a standard one-piece balsa wood sabot having a cylindrical pocket. No attempt was made to stop balsa wood sabots for this setup configuration; therefore, the balsa wood was permitted to impact the target specimens along with the desired impactor. The mass of the balsa wood sabot was added to the impactor mass to give the total impact mass for these impacts.

The final setup configuration used in the study was a setup using an 89 mm (3.5 inch) diameter smooth-bore launch tube having a length of 6.1 m (20.0 ft). A stopper section together with a vent section having a length of 1.83 m (6.0 ft) was used with the launch system. Molded urethane plastic sabots were utilized with the launch system to launch the impactor. Figure 3 shows the setup of the launch system. A metal target box was utilized to confine the target specimens as shown in Figure 3.

2.2.2 Blade and Specimen Mounting Procedure

All of the testing were conducted using the cantilivered method of mounting. The specimens were cantilever mounted in a vise-like fixture which conformed to the base cross-sectional geometry of the specimens. Each blade type used a special fixture to cantilever the blades. All of the fixtures were either directly or indirectly attached to the range "H" beam to provide a rigid and sturdy mounting system. The use of these mounting fixtures also permitted proper alignment and orientation of the targets with respect to the projectile trajectory.

In the case of the F101 blades, the tips were also restrained to simulate the tip shrouds in the actual engine. Figure 4 shows the system utilized to restrain the tip of the F101 blades.

2.2.3 Slice Size Determination

The mass of the projectile which actually impacts the target was of great importance in the leading edge impacts. The most satisfactory technique for determining the impact

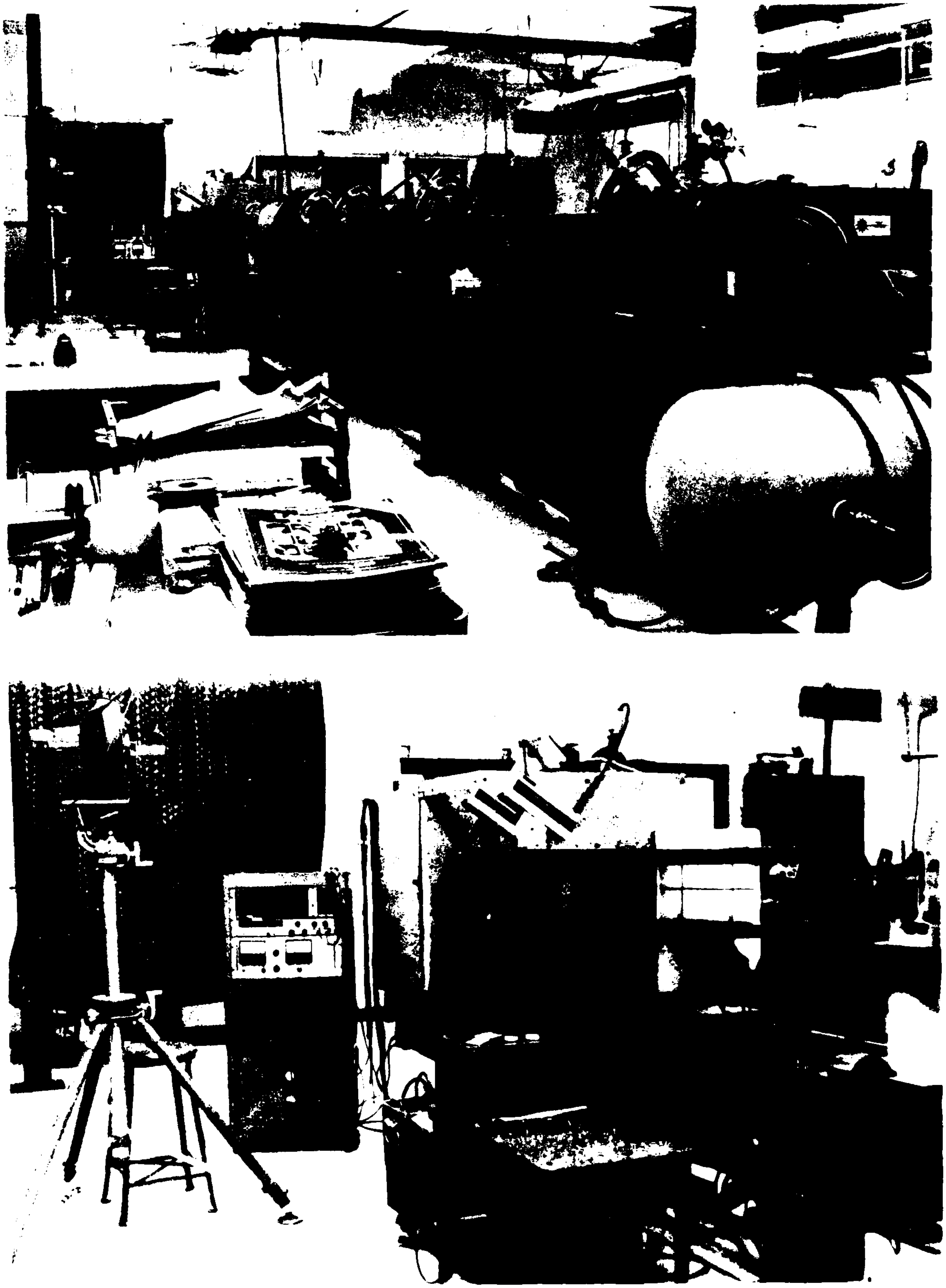


Figure 3. Photographs of Range Set-Up.

Figure 4. Photograph of Technique Utilized to Restrain F101 Blade Tips.

mass involved recovering the presliced portion and the non-deflected portion (slice across leading edge of the target) of the impactor and accurately weighing them. The mass recovered was then subtracted from the initial mass of the impactor to provide a reliable and accurate value for the impact slice mass.

2.2.4 Impact Velocity Measurements

The projectile velocity for the large bore compressed gas gun was measured by utilizing a pair of HeNe laser/photomultiplier stations spaced a known distance apart. Each laser projects a beam that intersects the projectile trajectory normal to trajectory and illuminates one of the photomultiplier stations. When the projectile interrupts the first beam, the first photomultiplier station generates a voltage pulse to start a counter-timer and trigger a light source for a still camera. The counter-timer is stopped and the other light source is triggered when the projectile interrupts the second laser beam. The projectile impact velocity was then calculated from the recorded measured time and the distance traveled. This technique provided accurate velocity measurements and also information on the integrity of the impactor just prior to impact.

2.3 DATA COLLECTION

The data collected and reported in detail in the Volume I report from the impact tests included accurate impact conditions, dynamic displacements of the specimens at discreet locations, strain/time histories local to the impact site and at critical blade stress regions identified from the structural response models, and damage assessment of the impacted targets. Each test was documented to record test conditions, test results, and damage results to permit an accurate interpretation of the results. These results could then be compared with the predictions from the analyses of Tasks V and VIII of the overall program.

2.3.1 Strain Measurements

The strain was detected utilizing high frequency strain gages mounted at critical locations on the target specimens and actual blades. Strain versus time and strain rate versus time curves were used to evaluate the results of the impacts. Gages were located at the root of the target specimens and blades in addition to several gages being positioned on the side of the targets opposite the impact site.

Digital data acquisition equipment was employed to record the data. The digital system has a "quick-look" capability which is very helpful in evaluating data early after the impact. The system has a 200 KHz bandwidth and a storage capability of 2048 data points. The data was recorded on cassette tapes to provide a permanent record of the strain data.

The significant local impact frequencies were estimated to extend to 20 KHz; therefore, low pass filters were used with the system to attenuate frequencies above 20 KHz. The sampling rate for the actual blade shot was 100 kHz while the sampling rate for the majority of the specimen impacts was 20 KHz.

The far field structural response was estimated to extend to about 4 KHz. Prior to impact testing on selected shots of the actual blades, frequency checks were made to establish the natural frequencies of the blades. In this case, the sampling rate used was 20 KHz with 4 KHz low-pass filters to attenuate frequencies above 4 KHz. After the impact was conducted the blades were again frequency checked to establish the natural frequencies. Any difference between the pre-test and post-test frequency checks would be attributed to blade damage due to the impact.

2.4 DAMAGE ASSESSMENT

The damage assessment portion of the data collected in the study was given particular consideration. The mode of

damage was determined and the extent of damage measured. It was anticipated that tests would be conducted on the impact damaged specimens and blades to determine the residual tensile strength and residual fatigue strength properties; however, the majority of the damage received was plastic deflections at the root area or actual breaking off at the root section for the blades and test specimens. This type of damage would not affect the residual tensile strength or fatigue strength to any extent.

2.4.1 Mode and Extent of Damage Measurements

The foreign object damage (FOD) problem can be divided into two separate areas, both of which are associated with a damage threshold. One deals with local blade or specimen damage; the other is associated with large scale structural damage. It was the purpose of this study to investigate and evaluate the damage for both the local and structural damage areas.

Since the impactors in the study were either artificial birds or ice, the damage mode for the metal materials usually was in the form of plastic deformation at the root area without cracking or curlback or a large amount of local bending at the impact site. In several cases, the specimens broke off at the root area. The local damage was characterized by measuring the maximum plastic deformation of the target leading edge (L.E.) and trailing edge (T.E.) whenever possible. Twist damage was also measured where specimens encountered twist damage. Plastic deformation at the root area was characterized by measuring the maximum deformation for the whole span length.

The damage for the APSI blade and test specimens was similar to that for the metal materials except that in several instances, material would be broken out at the impact site. This mass loss damage was characterized by making length and width measurements of the affected area. If plastic deformation was experienced, the damage was characterized by measuring the

the maximum deformation identical to the technique used for the metal materials.

In all cases, photographs of the damaged blades and test specimens were taken to document the damage. These photographs showing the impact damage were presented in the Volume I report describing in detail selected impacts for each group of structural specimens and actual blades.

SECTION 3
EXPERIMENTAL RESULTS

The experimental strain and strain rate results of the impact tests to investigate the response of test specimens ranging from simple cantilevered beams and plates to real blades from either artificial (substitute) birds or ice impacts are given in this report. A total of about 200 shots were fired to obtain 133 good impact data shots in the study. The majority of testing (92 shots) was conducted on simple element test specimens and 41 data shots were conducted on full scale blades.

3.1 SIMPLE ELEMENT TEST SPECIMENS

As indicated earlier, the three blade types investigated in the study included the F101 blade using 8-1-1 titanium, the J79 blade using 403 stainless steel, and the APSI blade using boron/aluminum material. These choices correspond to those which would be investigated analytically and experimentally in other tasks of the overall program. The geometries of the structural element test specimens were similar to the geometries of the actual blades at the 50 percent span location. The material, leading edge and trailing edge thickness, overall thickness, taper angle, chord width, and span length values of the test specimens were identical to that of the various blade types. These simple elements were tested with progressive introduction of airfoil geometric parameters to validate experimentally the analytical predictions of other tasks in the program and to derive a correlation between the structural element specimens and full scale blades.

Results of the static impact test on the structural element specimens are given in Table 8. The table gives the test conditions, specimen geometry and material type for each impact, the proper figure of Appendix A which describes the

TABLE 8. RESULTS OF STATIC IMPACT TESTING

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
1	4-0052	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.0	82.0	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade)	Center impact @ 70% span	22.5	No gauges	90.0	No	125.0	Plastic deformation of specimen at root; 1.35 cm deflection on left side and 1.51 cm deflection on right side measured at tip.	No film	--	No
1	4-0056	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.6	82.6	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade)	Center impact @ 70% span	22.2	No gauges	90.0	No	201.0	Plastic deformation of specimen at root; 7.62 cm deflection for both specimen sides measured at tip.	No film	--	No
1	2-0090	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	101.2	101.2	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	122.6	Plastic deformation of specimen at root; 1.98 cm deflection measured at tip.	Dynafax	20,800	Yes
1	2-0091	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	107.4	107.4	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	85.7	Plastic deformation of specimen at root; 0.71 cm deflection measured at tip.	Dynafax	20,752	Yes
1	2-0092	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	98.6	98.6	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	43.9	Plastic deformation of specimen at root; 0.15 cm deflection measured at tip.	No film	--	No
1	2-0093	Micro-ballon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	99.2	99.2	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	59.1	Plastic deformation of specimen through free span; 0.38 cm deflection measured at tip.	Hycam	Timing marks 1000/sec	Yes

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
1	2-0094	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	100.5	100.5	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	177.4	Plastic deformation of specimen at root; 6.50 cm deflection measured at tip.	Hycam	Timing marks 1,000/sec	Yes
1	2-0131	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.9	85.9	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	189.6	Plastic deformation of specimen at root and impact site; 5.69 cm deflection measured at tip.	Hycam	Timing marks 1,000/sec	Yes
2	2-0168	5.08 cm dia. ice ball	64.7	64.7	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	181.7	Plastic deformation of specimen at impact site; 0.32 cm bow measured at impact site. No strain gauge data.	No film	--	No
2	2-0169	5.08 cm dia. ice ball	63.5	63.5	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	183.8	Plastic deformation of specimen at impact site; 0.32 cm bow measured at impact site.	Dynafax	20,544	No
2	2-0170	5.08 cm dia. ice ball	62.4	62.4	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	130.0E	No strain gauge data or film. Velocity estimated. No visible damage on specimen.	No film	--	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
2	2-0171	5.08 cm dia. ice ball	62.5	62.5	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	116.5	No visible damage; projectile broke up upon launch.	Dynafax	20,464	No
2	2-0172	5.08 cm dia. ice ball	64.0	64.0	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	125.3	No visible damage on specimen.	Dynafax	20,736	No
2	2-0173	5.08 cm dia. ice ball	61.7	61.7	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	259.1	Specimen bowed 1.14 cm on right side and 1.40 cm on left side at impact site. Specimen twisted 0.46 cm. Impact hit off center to left side.	Dynafax	20,576	No
2	2-0174	5.08 cm dia. ice ball	65.9	65.9	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 30% span	9.3	See Figure 7A	90.0	No	262.2	Specimen bowed 1.68 cm on right side and 1.60 cm on left side at impact site. Specimen twisted 0.16 cm.	Dynafax	20,720	No
3	2-0111	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	81.8	18.1	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	36.4	No	86.6	No visible damage on specimen.	Dynafax	20,832	No
3	2-0112	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	80.0	23.3	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	36.4	No	110.1	No visible damage on specimen.	Dynafax	20,864	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
3	2-0113	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.6	54.9	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	36.4	No	188.4	No visible damage on specimen. Specimen moved in mount due to impact.	Dynafax	20,816	No
3	2-0114	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.6	45.9	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	36.4	No	191.2	No visible damage on specimen.	No film	--	No
3	2-0115	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.6	53.1	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	36.4	No	302.1	Plastic deformation at root and impact site. Leading edge deflection at tip-1.83 cm. Trailing edge deflection at tip-1.59 cm. Specimen twist through span-0.24 cm.	Hycam	Timing marks 1,000/sec	Yes
3	2-0121	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.2	66.2	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	36.4	No	445.7	No visible damage on specimen.	No film	--	No
3	2-0126	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	81.4	20.7	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	24.4	No	441.2	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	No
3	2-0127	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.0	22.8	8-1-1 Ti flat plate with blade-type aspect ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 8A	24.4	No	439.3	No visible damage specimen.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
4	2-0095	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	101.1	101.1	8-1-1 Ti flat plate with one-half blade-type aspect ratio of F101 blade	Center impact @ 70% span	10.9	See Figure 9A	90.0	No	52.7	Plastic deformation of specimen at root; 0.71 cm deflection measured at tip. Specimen mount moved due to impact.	Hycam	Timing marks 1,000/sec	No
4	2-0096	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	98.6	98.6	8-1-1 Ti flat plate with one-half blade-type aspect ratio of F101 blade	Center impact @ 70% span	10.9	See Figure 9A	90.0	No	99.4	Plastic deformation of specimen at root; 1.11 cm deflection measured at tip.	Hycam	Timing marks 1,000/sec	Yes
4	2-0097	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	95.9	95.9	8-1-1 Ti flat plate with one-half blade-type aspect ratio of F101 blade	Center impact @ 70% span	10.9	See Figure 9A	90.0	No	90.2	Plastic deformation of specimen at root; 0.71 cm deflection measured at tip.	Hycam	Timing marks 1,000/sec	Yes
4	2-0098	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	96.4	96.4	8-1-1 Ti flat plate with one-half blade-type aspect ratio of F101 blade	Center impact @ 70% span	10.9	See Figure 9A	90.0	No	150.6	Plastic deformation of specimen at root; 6.12 cm deflection measured at tip.	Hycam	Timing marks 1,000/sec	Yes
5	2-0193	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	678.3	79.3	8-1-1 Ti flat plate with one-half blade-type aspect ratio of F101 blade	Center impact @ 30% span	10.9	See Figure 10A	41.0	No	190.9	No visible damage on specimen. No strain gauge data or film.	No film	--	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
5	2-0194	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	668.1	154.5	8-1-1 Ti flat plate with one-half blade type aspect ratio of F101 blade	Center impact @ 30% span	10.9	See Figure 10A	41.0	No	191.8	No visible damage on specimen.	Dynafax	20,320	No
5	2-0195	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.6	79.9	8-1-1 Ti flat plate with one-half blade type aspect ratio of F101 blade	Center impact @ 30% span	10.9	See Figure 10A	41.0	No	232.3	No visible damage on specimen.	Dynafax	20,480	No
6	4-0053	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.1	83.1	8-1-1 Ti flat plate with blade-type aspect ratio and one-half blade-type thickness/chord ratio of F101 blade	Center impact @ 70% span	23.6	No gauges	90.0	No	74.9	Plastic deformation of specimen at root; 3.02 cm deflection on left side and 3.18 cm deflection on right side measured at tip.	No film	--	No
6	4-0054	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.5	83.5	8-1-1 Ti flat plate with blade-type aspect ratio and one-half blade-type thickness/chord ratio of F101 blade	Center impact @ 70% span	23.1	No gauges	90.0	No	126.1	Specimen broke off at root.	No film	--	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
6	4-0055	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.6	82.6	8-1-1 Ti flat plate with blade-type aspect ratio and one-half blade-type thickness/chord ratio of F101 blade	Center impact @ 70% span	22.5	No gauges	90.0	No	103.8	Plastic deformation of specimen at root; 10.95 cm deflection for both sides measured at tip.	No film	--	No
6	2-0175	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.2	85.2	8-1-1 Ti flat plate with blade-type aspect ratio and one-half blade-type thickness/chord ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	134.1E Velocity Estimated	Plastic deformation of specimen at root and impact site. Impact site deflection-0.81 cm. Tip deflection-15.24 cm on left side and 14.73 cm on right side. Specimen impacted 0.64 cm to left of center.	Dynafax	20,736	No
6	2-0176	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.3	85.3	8-1-1 Ti flat plate with blade-type aspect ratio and one-half blade-type thickness/chord ratio of F101 blade	Center impact @ 70% span	21.8	See Figure 7A	90.0	No	66.0	Plastic deformation of specimen at root. Tip deflection is 7.87 cm for both sides of specimen.	Dynafax	20,688	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
7	2-0128	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.6	35.1	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section) of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	323.2	Plastic deformation of specimen at leading edge at impact site. Impact site leading edge deflection-1.65 cm. Tip deflection is 1.14 cm for leading edge and 0.89 cm for trailing edge.	Hycam	Timing marks 1,000/sec	No
7	2-0129	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.2	13.7	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section) of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	135.4	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	No
7	2-0130	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.1	15.1	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section) of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	211.0	Plastic deformation on specimen leading edge at impact site with 0.16 cm bow.	Hycam	Timing marks 1,000/sec	Yes

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
8	2-0164	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	683.2	188.5	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	59.1	Plastic deformation on specimen leading edge at impact site with 0.16 cm bow.	Hycam	Timing marks 1,000/sec	No
8	2-0165	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	679.4	24.1	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	112.2	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	No
8	2-0166	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	699.2	120.1	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	189.0	Plastic deformation of specimen at root. Deflection of tip for leading edoe is 15.72 cm and 14.45 cm for trailing edge. Specimen twist measured 1.27 cm.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
8	2-0167	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	618.6	119.5	8-1-1 Ti plate with blade-type aspect ratio and airfoil shape (tapered cross section) of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	130.5	Plastic deformation of specimen at root. Deflection at tip for leading edge is 20.96 cm and 20.32 for trailing edge. Specimen twist measured 0.64 cm.	Hycam	Timing marks 1,000/sec	Yes
9	2-0180	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.0	329.2	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	122.3	Specimen broke off at root.	Dynafax	20,704	No
9	2-0181	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	649.2	138.1	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	61.9	No visible damage on specimen.	No film	--	No
9	2-0182	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.0	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	100.0E	No strain gauge data or film. Impact velocity estimated and impact mass not determined.	No film	--	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
9	2-0183	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.4	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	89.6	Bird hit target tank upon entry. No visible damage on specimen. Impact mass unable to be determined.	Dynafax	20,592	No
9	2-0184	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	670.0	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	100.3	No visible damage on specimen. Bird velocity to load specimen after being presliced too low to complete second slice by target specimen.	Dynafax	20,544	No
9	2-0185	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	680.0	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	114.0	No visible damage on specimen. Bird hit target tank upon entry. Impact mass unable to be determined.	Dynafax	20,688	No
9	2-0186	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	590.0	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	120.1	No visible damage on specimen. No film. Unable to determine impact mass.	No film	--	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
9	2-0187	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	675.0	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	151.2	No visible damage on specimen. No film. Unable to determine impact mass.	No film	--	No
9	2-0188	Micro-balloon latin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	675.2	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	183.0E	No visible damage on specimen. No film and velocity was estimated. Unable to determine impact mass.	Dynafax	20,816	No
9	2-0189	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	679.5	40.5	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	144.8	No visible damage on specimen.	Dynafax	20,704	No
9	2-0190	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.6	101.1	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	185.4	No visible damage on specimen.	Dynafax	20,224	Yes

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
9	2-0191	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	679.9	--	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span	21.8	See Figure 8A	24.4	No	239.9	No visible damage on specimen. Bird hit target tank upon entry. No film.	No film	--	No
9	2-0192	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	686.2	77.3	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Edge impact @ 70% span.	21.8	See Figure 8A	24.4	No	203.7	Severe damage. Specimen bent and broke at root area.	Dynafax	20,352	No
10	2-0177	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.3	85.3	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Center impact @ 70% span	21.8	See Figure 11A	90.0	Yes	126.5	Plastic deformation of specimen at impact site. Bow of 0.89 cm on left side of specimen and 0.95 cm on right side.	Dynafax	21,024	No
10	2-0178	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.3	84.3	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Center impact @ 70% span	21.8	See Figure 11A	90.0	Yes	29.3	No visible damage on specimen. Velocity estimated.	Dynafax	20,736	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
10	2-0179	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.3	85.3	8-1-1 Ti plate with blade-type aspect ratio and blade-like cross-section of F101 blade	Center impact @ 70% span	21.8	See Figure 11A	90.0	Yes	203.4	Shroud restraint tore loose from mount. Tip deflection of 17.59 cm on left side of specimen and 17.72 cm on right side.	Dynafax	20,688	No
11	2-0157	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	682.3	265.7	403 Stainless steel flat plate with blade-type aspect ratio of J79 blade	Edge impact @ 70% span	17.2	See Figure 12A	36.4	No	101.8	Specimen rocked back in mount. Plastic deformation of specimen at root by bending. Tip deflection of 17.24 cm of leading edge and 16.26 cm of trailing edge.	Hycam	Timing marks 1,000/sec	No
11	2-0158	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	652.8	253.8	403 Stainless steel flat plate with blade-type aspect ratio of J79 blade	Edge impact @ 70% span	17.2	See Figure 12A	36.4	No	54.3	No local damage; however, specimen bent at root. Tip deflection of 7.14 cm.	Hycam	Timing marks 1,000/sec	No
12	2-0159	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	666.7	~300.0	403 Stainless steel cambered flat plate with blade-type aspect ratio of J79 blade	Edge impact @ 70% span	17.2	See Figure 12A	36.4	No	47.9	No visible damage to specimen. Velocity low enough such that bird was not cut all the way through by specimen. Impact mass estimated.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
12	2-0163	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	712.7	172.3	403 Stainless steel cambered flat plate with blade-type aspect ratio of J 79 blade	Edge impact @ 70% span	17.2	See Figure 12A	36.4	No	92.4	Plastic deformation of specimen by bending at root. Tip deflection of 9.84 cm.	Hycam	Timing marks 1,000/sec	Yes
13	2-0161	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	606.4	148.6	403 Stainless steel cambered twisted plate with blade-type aspect ratio of J79 blade	Edge impact @ 70% span	17.2	See Figure 12A	36.4	No	63.7	Plastic deformation of specimen by bending at root. Tip deflection of 2.54 cm.	Hycam	Timing marks 1,000/sec	Yes
13	2-0162	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	692.0	192.3	403 Stainless steel cambered twisted plate with blade-type aspect ratio of J79 blade	Edge impact @ 70% span	17.2	See Figure 12A	36.4	No	98.5	Plastic deformation of specimen by bending at root. Tip deflection of 17.78 cm.	Hycam	Timing marks	No
14	2-0132 specimen # VI 3B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	8.4	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	85.1	No visible damage to specimen.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
14	2-0133 specimen # VI 1B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.6	12.9	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	105.8	No visible damage to specimen.	Hycam	Timing marks 1,000/sec	No
14	2-0134 specimen # VI 1A	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	87.5	10.7	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	161.9	Plastic deformation of specimen by bending at root. Tip deflection of 0.13 cm.	Hycam	Timing marks 1,000/sec	No
14	2-0135 specimen # VI 1B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.5	16.5	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	184.8	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	Yes
14	2-0136 specimen # VI 1B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.8	17.3	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	243.9%	Plastic deformation of specimen by bending at root. Tip deflection of 0.23 cm. Specimen also spalled and broke opposite impact site on leading edge over an area of 5.84 x 1.65 cm velocity estimated.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
14	2-0137 specimen # VI 3B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.0	15.9	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	256.1	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	No
14	2-0139 specimen # VI 3A	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.8	20.8	Boron/Al cross ply flat panel with blade-type aspect ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	312.8	Specimen broke at root. Tip deflection of 8.26 cm.	Hycam	Timing marks 1,000/sec	No
15	2-0149 specimen # VI 5A	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.3	~30.0	Boron/Al cross ply flat panel with one-half blade-type aspect ratio of APSI blade	Edge impact @ 70% span	5.4	See Figure 14A	18.9	No	185.4	No visible damage on specimen. Impact mass was estimated because bird hit "C" clamp in back of specimen.	Hycam	Timing marks 1,000/sec	No
15	2-0150 specimen # VI 5B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.6	23.8	Boron/Al cross ply flat panel with one-half blade-type aspect ratio of APSI blade	Edge impact @ 70% span	5.4	See Figure 14A	15.9	No	306.4	Specimen broke off at root.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
15	2-0151 specimen # VI 5A	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.6	46.1	Boron/Al cross ply flat panel with one-half blade-type aspect ratio of APSI blade	Edge impact @ 70% span	5.4	See Figure 14A	18.9	No	229.9	Specimen broke off at root.	Hycam	Timing marks 1,000/sec	No
16	2-0138 specimen # VI 7A	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.2	19.0	Boron/Al cross ply flat panel with blade-type aspect ratio and one-half blade-type thickness to chord ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	241.8	Specimen broke off at 70% span location at impact site.	Hycam	Timing marks 1,000/sec	No
16	2-0140 specimen # VI 7B	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.4	50.1	Boron/Al cross ply flat panel with blade-type aspect ratio and one-half blade-type thickness to chord ratio of APSI blade	Edge impact @ 70% span	10.8	See Figure 13A	18.9	No	119.5	Specimen broke off at root. Also broke off at 70% span location at impact site approximately 12.7 cm long along leading edge and 5.72 cm long along trailing edge from tip.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
17	2-0208	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	83.4	2.8	Boron/Al cross ply panel with blade-like cross-section	Edge impact @ 70% span	7.1	See Figure 15A	18.9	No	137.8	No visible damage. Bird tumbling during flight.	Dynafax	20,384	No
17	2-0209	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.2	4.5	Boron/Al cross ply panel with blade-like cross-section	Edge impact @ 70% span	7.1	See Figure 15A	18.9	No	122.9	No visible damage. Bird tumbling during flight.	Dynafax	20,240	No
17	2-0210	Micro-balloon gelatin bird (cylinder) (3.8 cm dia. x 7.62 cm long)	80.0	0.0	Boron/Al cross ply panel with blade-like cross-section	Edge impact @ 70% span	7.1	See Figure 15A	18.9	No	121.0	No visible damage. Bird missed specimen.	No film	--	No
17	2-0211	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.0	5.3	Boron/Al cross ply panel with blade-like cross-section	Edge impact @ 70% span	7.1	See Figure 15A	18.9	No	133.8	No visible damage on specimen.	Dynafax	20,368	No
17	2-0212	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	81.7	8.0	Boron/Al cross ply panel with blade-like cross-section	Edge impact @ 70% span	7.1	See Figure 15A	18.9	No	194.2	No visible damage on specimen.	Dynafax	20,448	Yes

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
17	2-0213	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	81.5	31.7	Boron/Al cross ply panel with blade-like cross-section	Edge impact @ 70% span	7.1	See Figure 15A	18.9	No	247.3	Specimen broke into many smaller type pieces at impact site area.	Dynafax	20,224	No
18	2-0143 specimen # VI AP2	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.9	3.1	Boron/Al cross ply constant chord air-foil panel with blade-type aspect ratio and camber	Edge impact @ 70% span	10.8	See Figure 16A	18.9	No	138.7	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	No
18	2-0144 specimen # VI AP1	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	82.8	6.7	Boron/Al cross ply constant chord air-foil panel with blade-type aspect ratio and camber	Edge impact @ 70% span	10.9	See Figure 16A	18.9	No	202.7	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	Yes
18	2-0145 specimen # VI AP3	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	87.3	35.6	Boron/Al cross ply constant chord air-foil panel with blade-type aspect ratio and camber	Edge impact @ 70% span	10.8	See Figure 16A	18.9	No	319.8	Specimen broke off at root and also just below 70% span location.	Hycam	Timing marks 1,000/sec	No

TABLE 8. RESULTS OF STATIC IMPACT TESTING (CONCLUDED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Root (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
19	2-0146 specimen # VI AF 25	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.6	47.0	Boron/Al cross ply constant chord airfoil panel with blade-type aspect ratio, camber, and twist	Edge impact @ 70% span	10.8	See Figure 16A	18.9	No	208.8	Specimen broke off at root.	Hycam	Timing marks 1,000/sec	No
19	2-0147 specimen # VI AF 24	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.7	11.2	Boron/Al cross ply constant chord airfoil panel with blade-type aspect ratio, camber, and twist	Edge impact @ 70% span	10.8	See Figure 16A	18.9	No	159.1	No visible damage on specimen.	Hycam	Timing marks 1,000/sec	Yes
19	2-0148 specimen # VI AF 22	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.9	33.1	Boron/Al cross ply constant chord airfoil panel with blade-type aspect ratio, camber, and twist	Edge impact @ 70% span	10.8	See Figure 16A	18.9	No	185.7	Specimen broke off at root.	Hycam	Timing marks 1,000/sec	No

strain gage locations, the impact mass loading the specimens, the span location and type of impact, and a description of the damage generated on each specimen. Appendix A presents Figures 1A through 16A which are sketches showing the strain gage locations for both specimen and real blade impacts.

As indicated earlier, 93 impacts were conducted on structural element test specimens. Five of the specimens in this testing were tested without strain gages to measure out-of-plane displacements of a specimen surface using the Moiré fringe apparatus. The remaining impact tests were conducted using specimens instrumented with six strain gages. High speed photography was also used in every test where strain gages were installed on the specimens.

The strain was detected using high frequency strain gages mounted at critical locations of the test specimens and actual blades. Strain versus time and strain rate versus time plots were used to evaluate the results of the impacts. Gages were located at the root of the cantilevered test specimens and blades in addition to several gages being positioned directly opposite the impact site. The majority of the specimen tests were conducted using a sampling rate of 20 KHz on the strain data acquisition equipment with 4 KHz low-pass filters.

3.1.1 Impact Results of Structural Element Tests

The testing involved conducting either center or leading-edge impacts on 19 different groups of structural element specimens. As indicated earlier, the impactors were either artificial birds or ice projectiles which were fired on the cantilevered specimens. In several cases, the specimen tip was also restrained to simulate a tip shroud. The strain and strain rate data resulting from the impact are presented in Appendix B in the form of plots of strain and strain rate versus time. Tension is characterized as a positive strain value while compression is a negative strain for all cases unless noted.

The impact velocity was varied in the testing from a low velocity range to generate elastic deformation response (no visible damage), to a medium range to generate plastic deformation (threshold damage), and finally a high velocity range where plastic/tear deformations were produced (severe damage).

3.2 IMPACT RESULTS ON ACTUAL BLADES

The testing involved conducting leading edge impacts on the three blade types investigated in the program. Various test conditions were used to determine the impact response of the blades. Tests were performed on 15 groups of blades as presented in Table 6 given earlier in this report. The impactors were either artificial birds or ice projectiles (both slab ice and spheres) in the study on the actual blades. The F101 blade using 8-1-1 titanium has a tip shroud which was restrained. The tip shroud was permitted to move in the spanwise direction during the impact event as shown in Figure 4. The strain and strain rate data resulting from the impacts are presented in Appendix B in the form of strain and strain rate versus time plots. Two sizes of birds were utilized in the testing (85 g and 680 g). The 85 g (3 ounce) bird was used to simulate a starling sized bird and the 680 g (1.5 pound) bird would be a seagull sized bird. The ice impactors used in the study were either a cylinder 7.62 cm (3.0 inches) diameter with a length of 17.78 cm (7.0 inches) or a 5.08 cm (2.0 inch) ice sphere. The ice cylinder (mass of 850 g) was used to simulate an ice slab while the ice sphere (mass of 65 g) simulated hail size ice balls. The impact site was either at the 30 percent or 70 percent span locations.

Table 9 gives the results of the impact tests for the actual blades. The table gives the test conditions, the blade and material type, the proper figure of Appendix A which

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONCLUDED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
14B	2-0217 Blade #040	Ice ball (5.08 cm dia. sphere)	69.8	~34.9	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 5A	38.8	No	79.0	No visible damage on blade, projectile broke up upon launch. No strain gauge data. Impact mass estimated to be half of initial ice ball mass.	No film	---	No
14B	2-0218 Blade #040	Ice ball (5.08 cm dia. sphere)	68.3	~34.2	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 5A	38.8	No	92.7	Severe damage by breaking out 5.08·1.27 cm (length·width) section of leading edge at impact site. Impact mass estimated to be half of initial ice ball mass.	Dynafax	20,160	No
15B	2-0233 Blade #068	Ice cylinder (7.62 cm dia. x 17.78 cm long)	716.1	135.7	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 5A	38.8	No	96.0	Severe damage by breaking off at platform close to root area and breaking out 9.65·1.52 cm (length·width) section of leading edge at impact site.	Dynafax	20,304	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
12B	2-0023 Blade #073	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	---	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 3A	38.8	No	418.9	Blade cracked along platform across chord 5.08 cm starting at leading edge side. Sabot also impacted blade. Unable to determine impact mass	Dynafax	20,912	Yes
13B	2-0022 Blade #059	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	---	Boron/ aluminum APSI blade	Edge impact @ 70% span	10.8	see Fig. 3A	18.9	No	406.1	Blade broke off along platform close to root area. Also broke out material at tip 10.16 cm down along leading edge and 2.29 cm width. Unable to determine impact mass.	Dynafax	20,784	Yes
14B	2-0214 Blade #076	Ice ball (5.08 cm dia. sphere)	62.0	~31.0	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 5A	38.8	No	133.8	No visible damage on blade. Projectile broke up upon launch. Impact mass estimated to be half of initial ice ball mass.	No film	--	No
14B	2-0215 Blade #076	Ice ball (5.08 cm dia. sphere)	65.3	~32.7	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 5A	38.8	No	198.8	Blade bowed 0.25 cm on leading edge at impact site. Projectile broke up upon launch. Impact mass estimated to be half of initial ice ball mass.	Dynafax	20,224	No
14B	2-0216 Blade #046	Ice ball (5.08 cm dia. sphere)	65.4	~32.7	Boron/ aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 5A	38.8	No	132.3	Severe damage by breaking out 6.60·1.27 cm (length·width) section of leading edge at impact site. Impact mass estimated to be half of initial ice ball mass.	No film	--	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
10B	2-0226 Blade #1-2	Ice ball (5.08 cm dia. sphere)	64.6	32.3	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	324.7	Plastic deformation of bowing at impact site. Bow of 1.58 cm along leading edge. Tip deflection of 5.13 cm at leading edge and 8.49 cm at trailing edge. Impact mass estimated to be half of ice sphere.	Dynafax	20,368	No
11B	2-0232 Blade #1-3	Ice cylinder (7.62 cm dia. x 17.78 cm long)	686.5	147.8	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	99.4	No visible damage on specimen.	No film	--	No
11B	2-0234 Blade #1-4	Ice cylinder (7.62 cm dia. x 17.78 cm long)	758.5	207.4	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	97.6	No visible damage on specimen.	Dynafax	20,288	Yes
11B	2-0235 Blade #1-4	Ice cylinder (7.62 cm dia. x 17.78 cm long)	688.6	158.4	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	133.6	Plastic deflection of bowing at impact site. Tip deflection of 14.70 cm along leading edge and 15.49 cm along trailing edge.	Dynafax	20,240	No
12B	2-0016 Blade #082	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	16.0	Boron/aluminum APSI blade	Edge impact @ 30% span	4.4	see Fig. 3A	38.8	No	259.1E	Local damage at impact site by breaking off material along leading edge. Affected area was 7.13 cm long and 1.80 cm maximum width.	No film	--	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
8B	2-0015 Blade #2	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	680.0	311.0	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	170.7	Blade severely damaged by being knocked from fixture. General bowing through free span with tip deflection of 8.15 cm.	No film	--	No
9B	2-0024 Blade #3	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	680.0	161.0	403 Stainless steel J79 blade	Edge impact @ 70% span	16.8	see Fig. 2A	36.4	No	254.0	Blade severely damaged by being knocked from fixture. Specimen hit target tank. Large amount of bow damage of 9.8 cm at impact site.	Dynafax	20,800	Yes
10B	2-0219 Blade #1-1	Ice ball (5.08 cm dia. sphere)	65.6	~32.8	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	88.7	No visible damage on specimen. Impact mass estimate to be half of ice sphere.	Dynafax	20,384	Yes
10B	2-0220 Blade #1-1	Ice ball (5.08 cm dia. sphere)	65.0	~32.5	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	139.4	No visible damage on specimen. Impact mass estimated to be half of ice sphere.	Dynafax	20,384	No
10B	2-0221 Blade #1-2	Ice ball (5.08 cm dia. sphere)	63.5	~31.8	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	182.3	No visible damage on specimen. Ice ball broke up upon launch. Impact mass estimated to be half of ice sphere.	Dynafax	20,288	No
10B	2-0222 Blade #1-1	Ice ball (5.08 cm dia. sphere)	65.2	~32.6	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 6A	51.1	No	247.9	General bending from root to tip through free span. Tip deflection of 2.24 cm. Impact mass estimated to be half of ice sphere.	Dynafax	20,336	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
7B	2-0021 Blade #1	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	28.0	403 Stainless steel J79 blade	Edge impact @ 70% span	16.8	see Fig. 2A	36.4	No	300.0	Sabot impacted blade. Blade damaged by bowing at impact site. Bow of 5.38 cm at leading edge; 4.08 cm at trailing edge.	Dynafax	20,896	No
8B	2-0011 Blade #1	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	679.0	94.9	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	160.7	Blade damaged slightly by bowing at impact site of 0.25 cm.	Dynafax	20,786	No
8B	2-0012 Blade #2	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	668.0	---	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	161.6	No visible damage on specimen. No strain gauge data. Unable to determine impact mass.	No film	--	No
8B	2-0013 Blade #2	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	678.5	---	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	167.4	No visible damage on specimen. Unable to determine impact mass.	No film	--	No
8B	2-0014 Blade #2	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	660.0	37.0	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	170.4	No visible damage on specimen.	Dynafax	20,720	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
5B	2-0229 Blade# KGA01582	Ice cylinder (7.62 cm dia. x 17.78 cm long)	835.8	---	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	93.9	No visible damage on specimen. Ice cylinder broke up upon launch.	Dynafax	20,368	No
5B	2-0230 Blade# KGA01582	Ice cylinder (7.62 cm dia. x 17.78 cm long)	841.4	---	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	92.7	No visible damage on specimen. Ice cylinder broke up upon launch.	Dynafax	20,560	No
5B	2-0231	Ice cylinder (7.62 cm dia. x 17.78 cm long)	867.1	75.8	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	185.1	Blade bowed at impact site 5.28 cm on leading edge and 6.50 cm on trailing edge.	Dynafax	20,464	Yes
6B	2-0008 Blade #1	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.5	15.1	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	164.3	No visible damage on specimen.	No film	---	No
6B	2-0009 Blade #1	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	84.3	48.1	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	161.3	No visible damage on specimen.	No film	---	No
6B	2-0010 Blade #1	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	48.1	403 Stainless steel J79 blade	Edge impact @ 30% span	7.2	see Fig. 2A	51.1	No	200.3	No visible damage on specimen.	Dynafax	20,896	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES (CONTINUED)

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
4B	2-0197 Blade# KGA01476	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.4	64.3	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	117.7	No visible damage on specimen.	Dynafax	20,160	No
4B	2-0198 Blade# KGA01476	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	681.4	40.7	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	121.3	No visible damage on specimen.	Dynafax	20,288	No
4B	2-0199 Blade# KGA01476	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	683.0	124.3	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	187.2	No visible damage on specimen.	Dynafax	20,192	No
4B	2-0200 Blade# KGA01476	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	675.2	---	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	230.5	No visible damage on specimen. Unable to determine impact mass.	Dynafax	20,240	No
4B	2-0201 Blade# KGA01476	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	683.6	105.6	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	183.2	Blade knocked out of bottom fixture. Blade bowed at impact site 1.78 cm.	Dynafax	20,336	No
5B	2-0228 Blade# KGA01582	Ice Cylinder (7.62 cm dia. x 17.78 cm long)	786.8	---	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	95.4	No visible damage on specimen. Ice cylinder broke up upon launch.	Dynafax	20,416	No

TABLE 9. RESULTS OF STATIC IMPACT TESTING ON ACTUAL BLADES

Group No.	Shot No.	Projectile Type	Projectile Mass (g)	Mass Impacting Target (g)	Target Material and Description	Span Location for Impact (%)	Impact Distance from Platform (cm)	Strain Gauge Locations	Impact Angle (°)	Shroud Restraint	Impact Velocity (m/s)	Damage Description and Comments	High-Speed Camera Type	Camera Framing Rate (frames/sec)	Deformation Plot
1B	2-0017 Blade # KGA00017	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	25.0	8-1-1 Ti F101 blade	Edge impact @ 30% span	8.0	see Fig. 1A	41.0	Yes	269.5	No visible damage specimen.	Dynafax	20,832	No
2B	2-0018 Blade # KGA00172	Micro-balloon gelatin bird (cylinder) (3.81 cm dia. x 7.62 cm long)	85.0	---	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 1A	24.4	Yes	353.4	No visible damage on specimen. Unable to determine impact mass.	Dynafax	20,752	No
3B	2-0019 Blade # KGA00017	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	672.0	---	8-1-1 Ti F101 blade	Edge impact @ 30% span	8.0	see Fig. 1A	41.0	Yes	259.1E	Sabot impacted blade. Blade damaged slightly by leading edge bow of 0.13 cm. Velocity estimated. Unable to determine impact mass.	Dynafax	20,784	No
4B	2-0020 Blade # KGA00172	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	678.0	214.0	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 1A	24.4	Yes	259.1E	Blade damaged due to sabot impacting specimen. Velocity estimated. Blade damaged by bowing at impact site. 3.00 cm bow on leading edge and 3.81 cm bow on trailing edge.	Dynafax	20,800	No
4B	2-0196 Blade # KGA01476	Micro-balloon gelatin bird (cylinder) (7.62 cm dia. x 15.24 cm long)	679.7	27.4	8-1-1 Ti F101 blade	Edge impact @ 70% span	18.6	see Fig. 4A	24.4	Yes	106.7E	No visible damage on specimen. Velocity estimated.	Dynafax	20,096	No

describes the strain gage locations, the impact velocity and mass, the span location and type of impact, and a description of the damage generated on each blade.

As indicated earlier, 41 impacts were conducted on actual blades. All of the blades were instrumented with six strain gages. The sampling rate for the actual blade shots was 100 KHz and 20 KHz low-pass filters were used for this sampling rate. Frequency checks were also made on selected blades before and after each test. Any difference between the pretest and post-test frequency checks may be attributed to damage on the blade. These frequency checks were conducted at a sampling rate of 20 KHz with 4 KHz low-pass filters to attentuate frequencies above 4 KHz.

The impact velocity was also varied for the blade tests from a low velocity range to generate elastic deformation response (no visible damage), to a medium range to generate plastic deformation (threshold damage), and finally a high velocity range, where plastic/tear deformations were produced (severe damage). Tension is characterized as a positive strain value while compression is a negative strain for all cases except for Shots 2-0008 through 2-0024. In these cases, a negative strain denotes tension and a positive strain denotes compression.

SECTION 4
SUMMARY AND CONCLUSIONS

The experimental program (Task VI) involved conducting nonrotating bench impact tests on test specimens ranging from simple cantilevered beams and plates to real blades. The response of the test specimens to impacts of substitute birds or ice was determined in the testing. The data collected included accurate impact conditions, dynamic displacement of the specimens at discreet points, strain/time histories local to the impact site and at critical blade stress regions identified from the structure response models, and damage assessment. The simple elements, such as beams or plates, were tested with progressive introduction of airfoil geometric parameters to validate experimentally the analytical predictions of Tasks V and VIII of the overall program and to derive a correlation between structural elemented specimens and full-scale blades.

Three types of blade materials, geometries, and sizes were investigated using ice and substitute birds as the impactors. The three blade types investigated in the study were the F101 blade using 8Al-1MO-IV (8-1-1) titanium, the J79 blade using 403 stainless steel, and the APSI metal matrix boron/aluminum blade. The geometries of the test specimens were similar to the geometries at the 50 percent span location of the three blade types investigated.

A baseline series of tests was conducted on the titanium material, a supplementary series was conducted on the stainless steel material, and a more complete series was conducted on the advanced composite material. The geometry effects which were believed to effect impact response were independently introduced in the testing and analysis. These effects included the aspect ratio, thickness to chord ratio, shape, shrouds, camber, and twist.

Four impactors were used in the testing which included 85 g (3 ounce) and 680 g (1.5 pound) artificial birds, a 50.8 mm (2 ounce) ice ball, and 750 g (1.65 pound) ice cylinders to simulate slab ice. The impactors were gun launched to impact the leading edge of the test specimens in the majority of the testing.

A total of 92 impacts were conducted on the simple element test specimens. All of the specimens were strain gaged (except for the Moiré fringe shots) to obtain strain/time histories of the specimens local to the impact site and at critical blade stress regions for an impact. The impact velocity for the impacts was varied to obtain no damage, threshold damage, and severe damage on the specimens. The damage assessment of the data collected in the study included determining the mode of damage and measuring the extent of damage.

In addition to impact testing of simple element specimens, a number of impact tests (41 shots) were also conducted on full scale component blades. This impact testing of the actual blades was coordinated with the full scale blade testing of Task IVA where the impact tests were conducted to establish the strain rate limits for the material property tests of Task IVA. The impact velocities used in the Task IVA tests corresponded to those which would be typical of an impact at 70 percent span and 30 percent span locations at full power settings of the engine during takeoff for each of the blade types. Impacts at the 70 percent span level are representative of the highest velocity impacts experienced by a blade. Impacts at the 30 percent span level are typical of those in the highest stress regions of the blade where it is most vulnerable to the effects of impact degradation. The impact tests of Task IVA indicated that the highest strain rates developed were less than 400 in/in/sec in any of the types of blades tested (J79, F101, and APSI).

All of the strain and strain rate plots versus time are given in Appendix B for all impacts.

Appendix B is contained in two separate volumes of 11 x 13 sheets of graph paper. One of the volumes contains the data for shots 2-0008 through 2-0024 inclusive, shots 2-0090 through 2-0098 inclusive, shots 2-0111 through 2-0115 inclusive, shots 2-0115, 2-0121, and 2-0126 through 2-0150 inclusive, shots 2-0157 and 2-0158. The second volume of Appendix B contains the data for shots 2-0159 through 2-0167 inclusive, shot 2-0169, shots 2-0171 through 2-0181 inclusive, shots 2-0183 and 2-0184, shots 2-0186 through 2-0190, shot 2-0192, shots 2-0194 through 2-0201, shots 2-0206 through 2-0209 inclusive, shots 2-0211 through 2-0216 inclusive, shots 2-0218 through 2-0222, shot 2-0226, and shots 2-0228 through 2-0234 inclusive. Each volume contains approximately 800 pages of graphs. The University does not plan to retain copies of these graphs and has delivered the originals to the General Electric Company.

APPENDIX A

STRAIN GAGE LOCATIONS

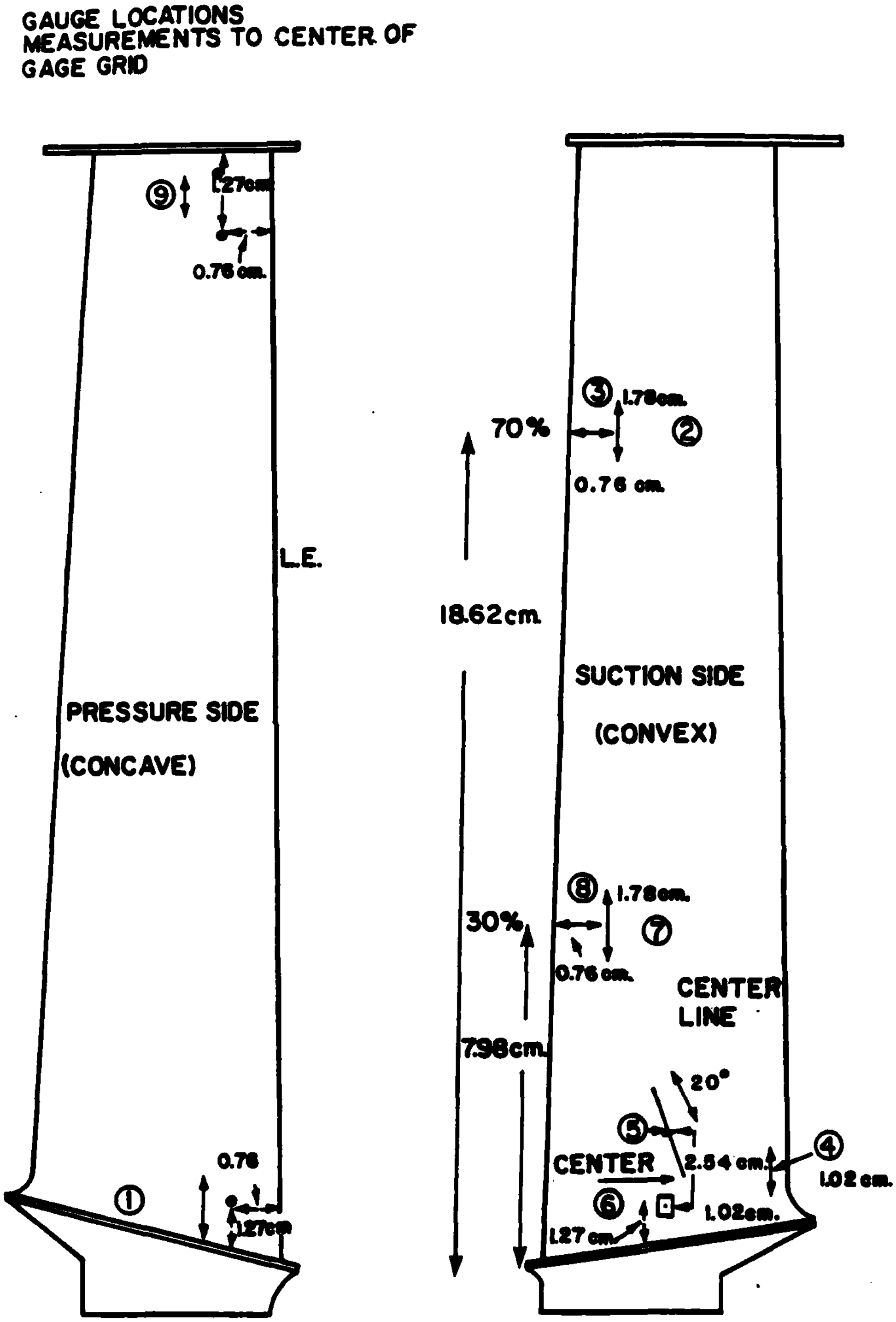


Figure 1A. Strain Gage Locations for Group 1B, 2B, 3B, and 4B Blades.

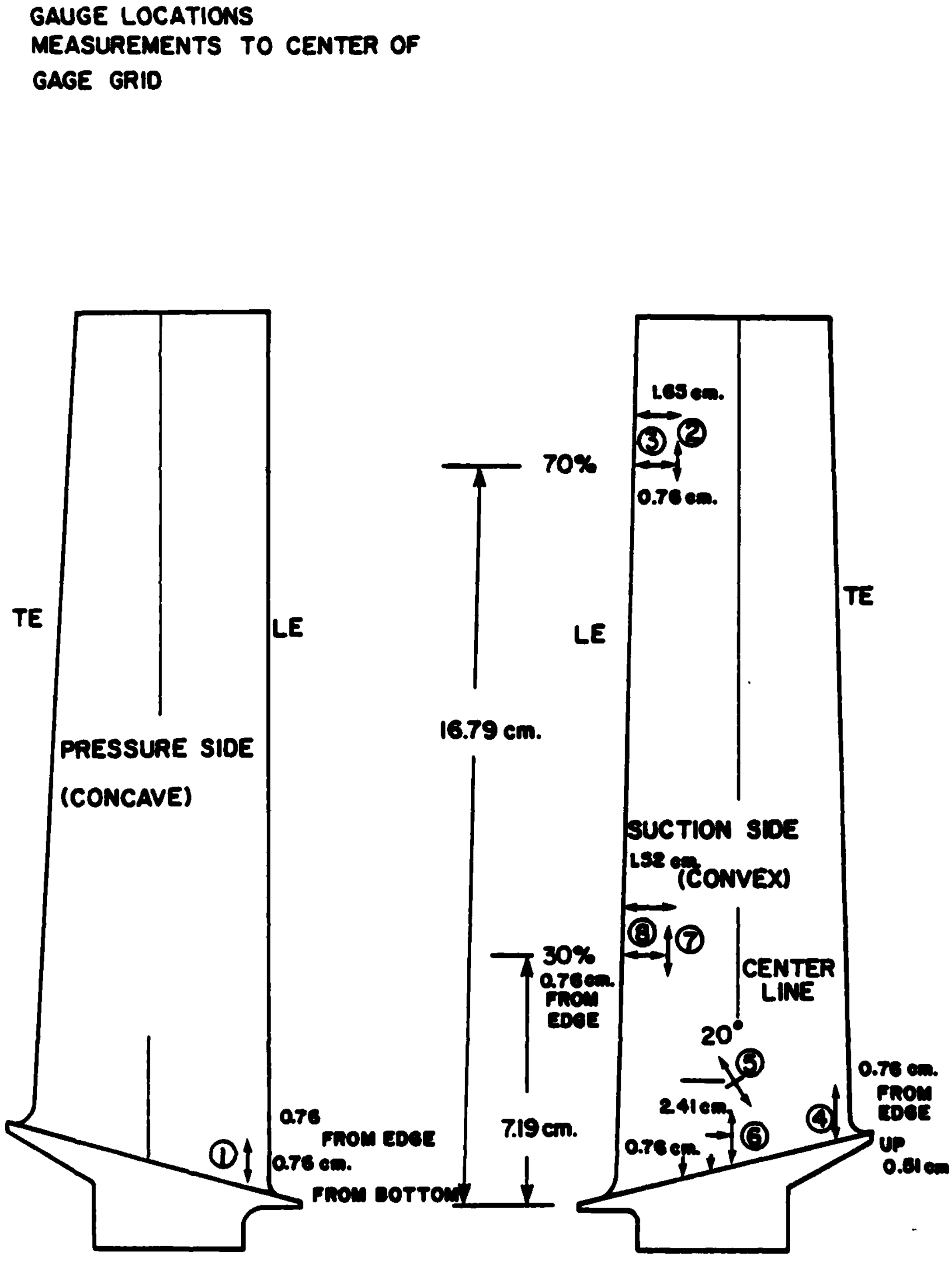


Figure 2A. Strain Gage Locations for Group 6B, 7B, 8B, and 9B Blades.

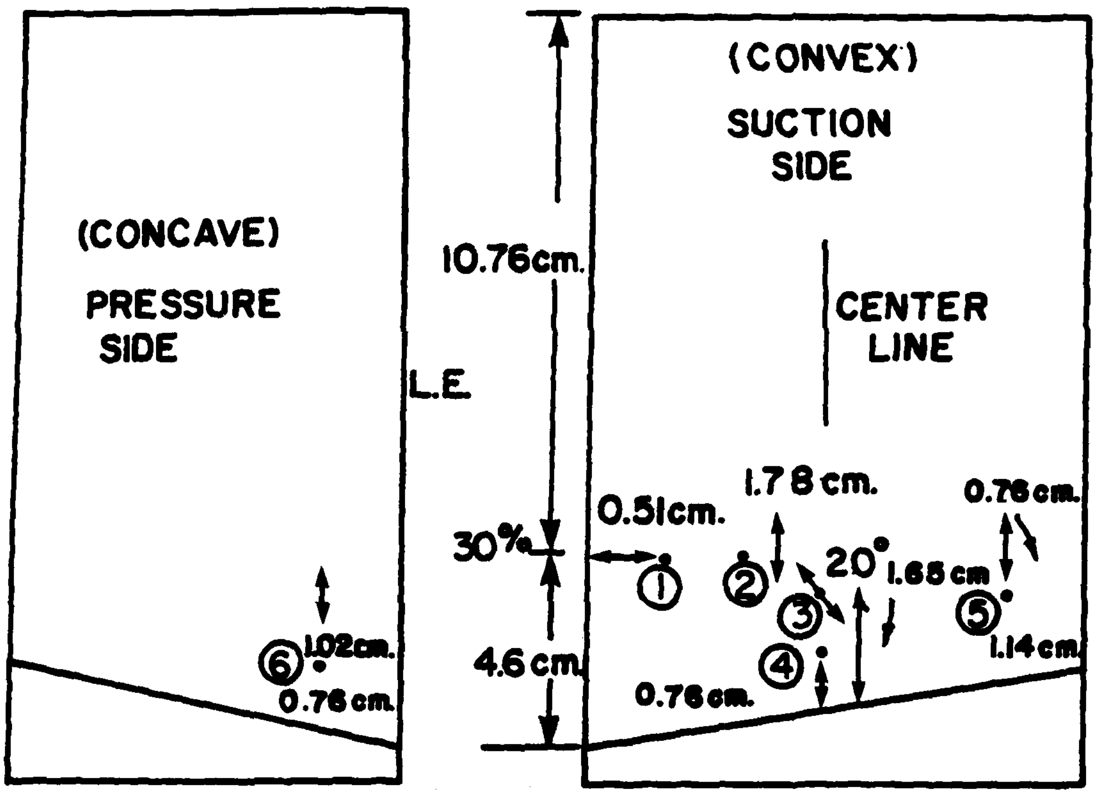


Figure 5A. Strain Gage Locations for Group 14B and 15B Blades.

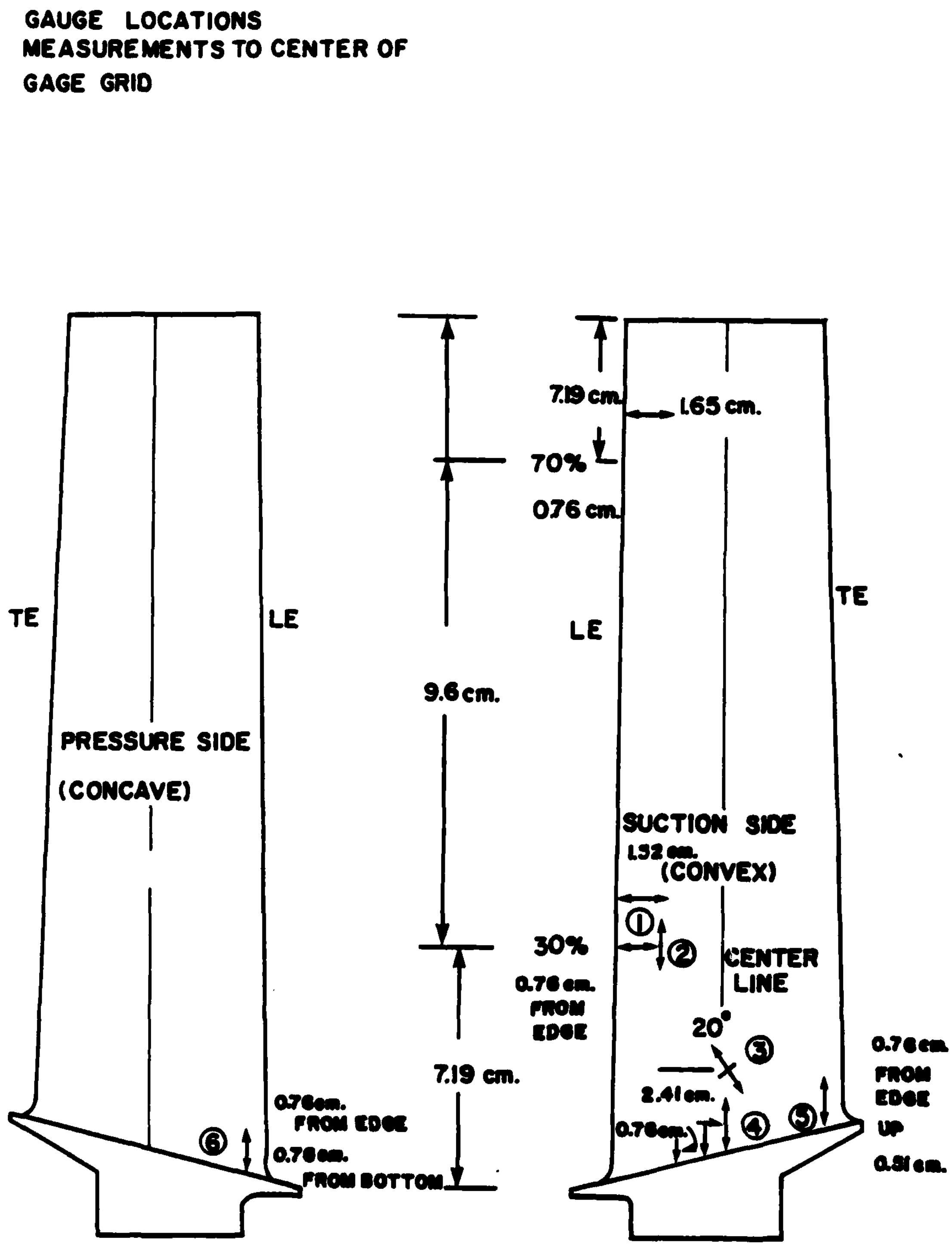


Figure 6A. Strain Gage Locations for Group 10B and 11B Blades.

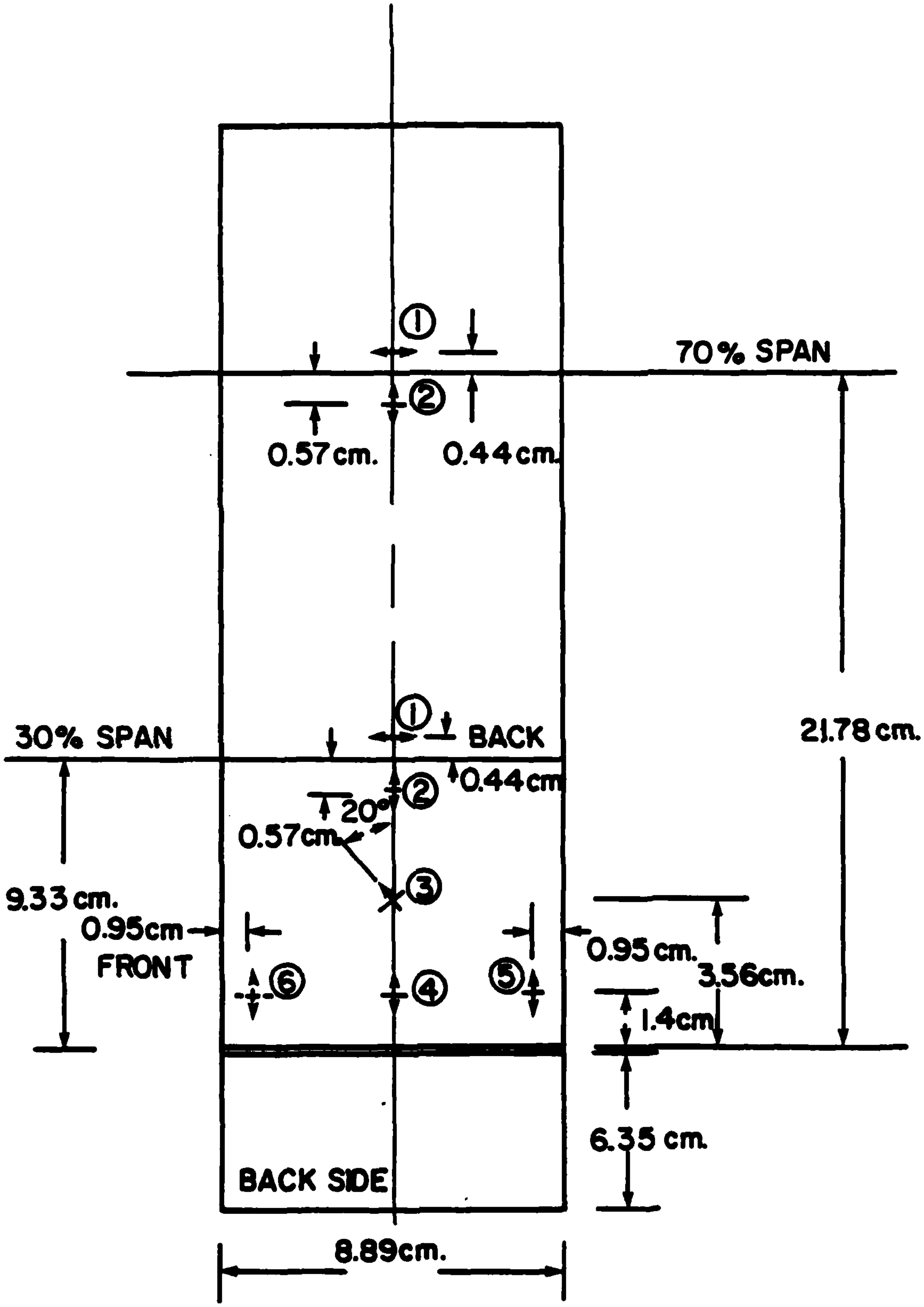


Figure 7A. Strain Gage Locations for Group 1, 2, and 6 Structural Element Test Specimens.

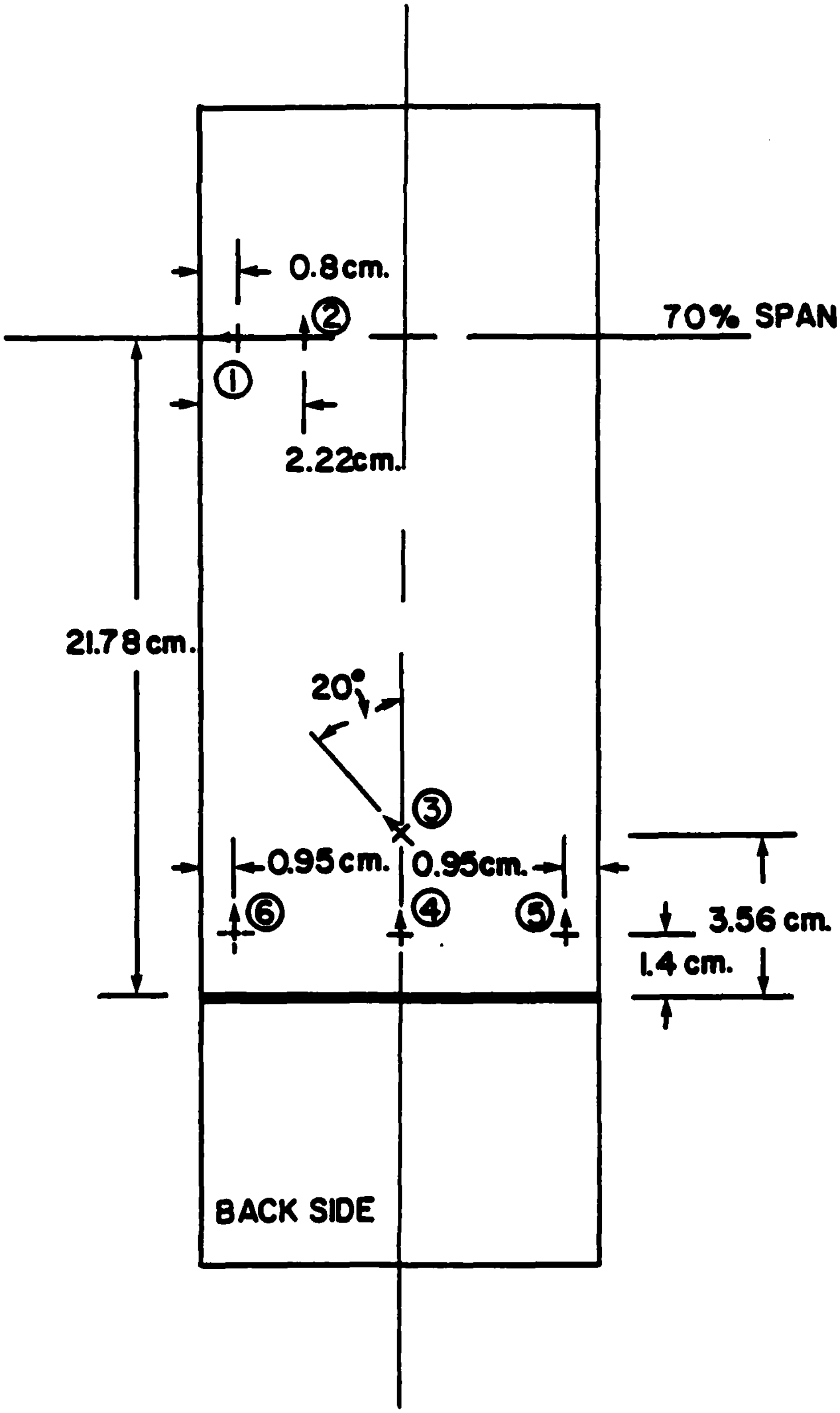


Figure 8A. Strain Gage Locations for Group 3, 7, 8, and 9 Structural Element Test Specimens.

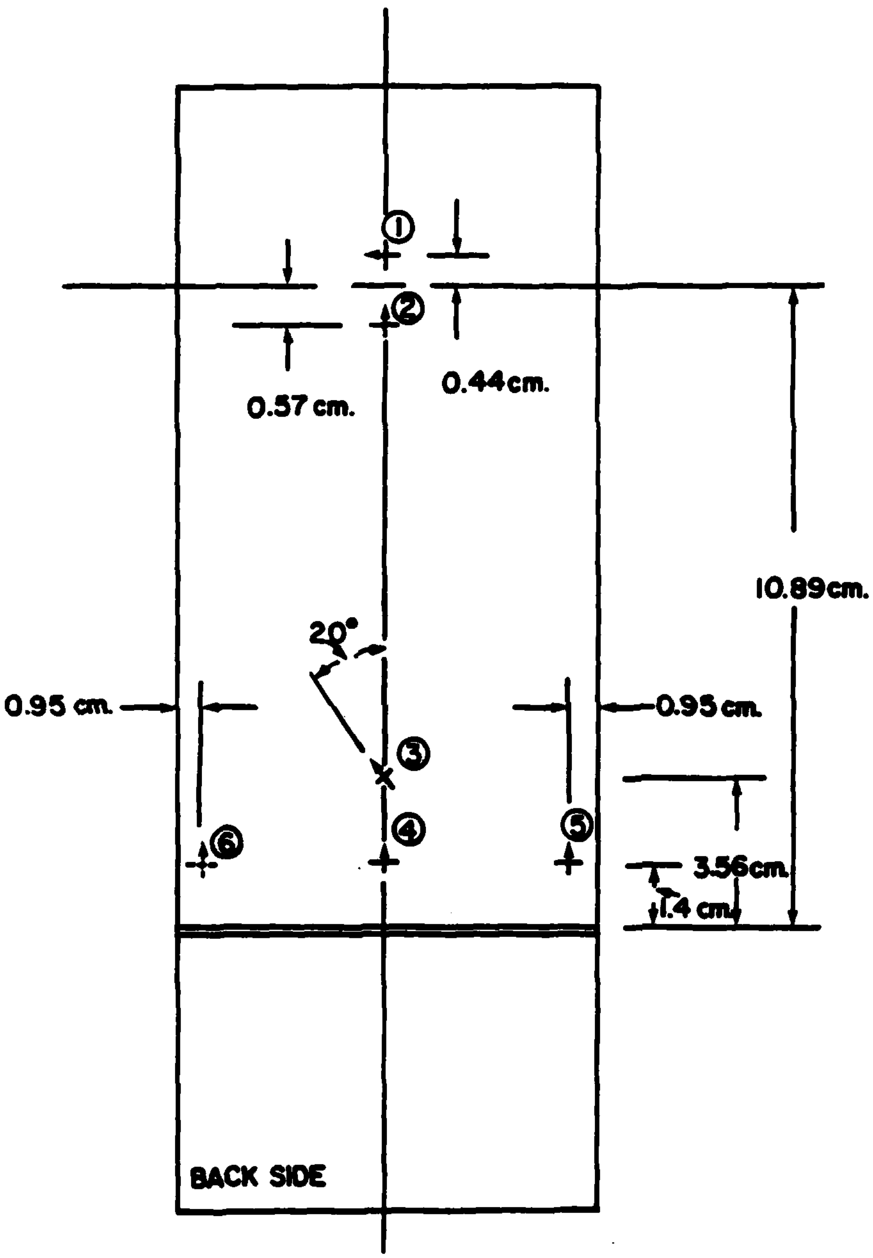


Figure 9A. Strain Gage Locations for Group 4 Structural Element Test Specimens.

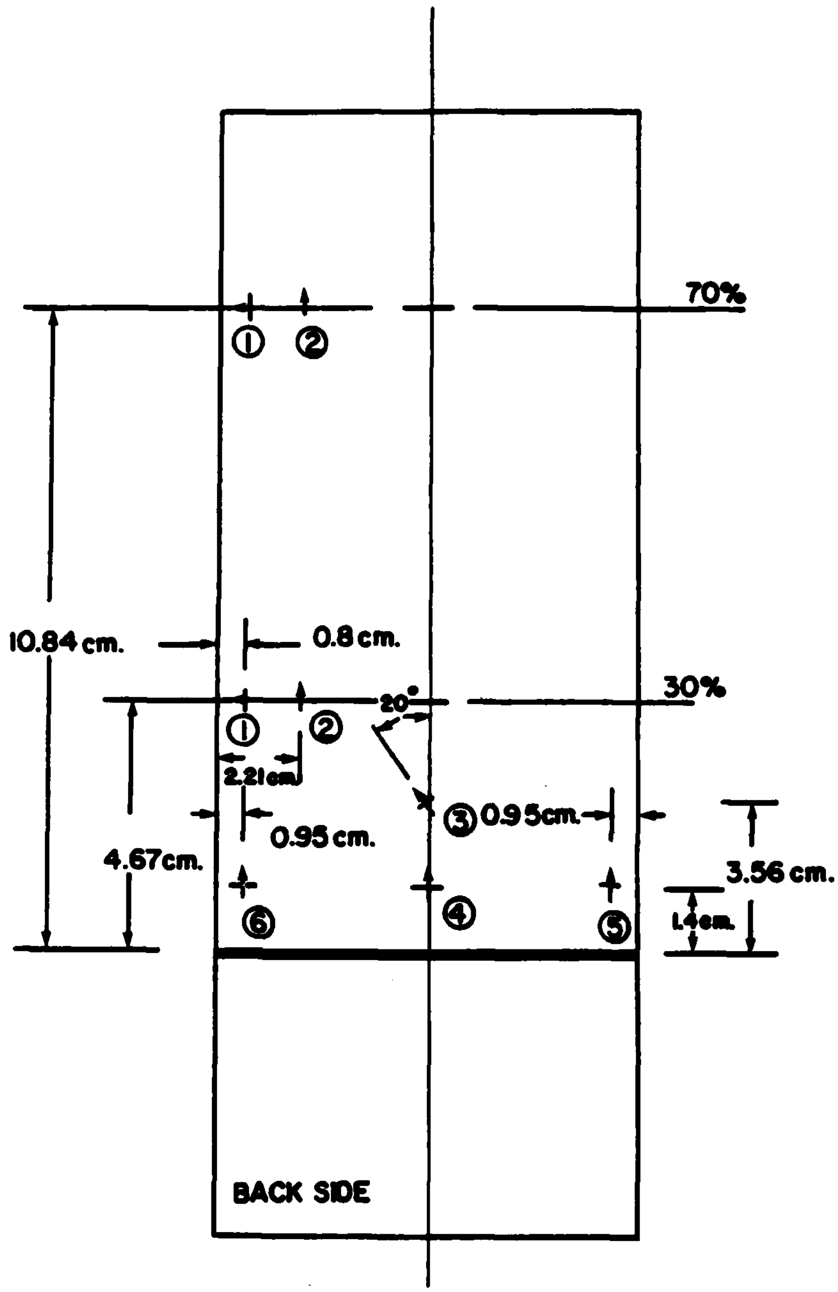


Figure 10A. Strain Gage Locations for Group 5 Structural Element Test Specimens.

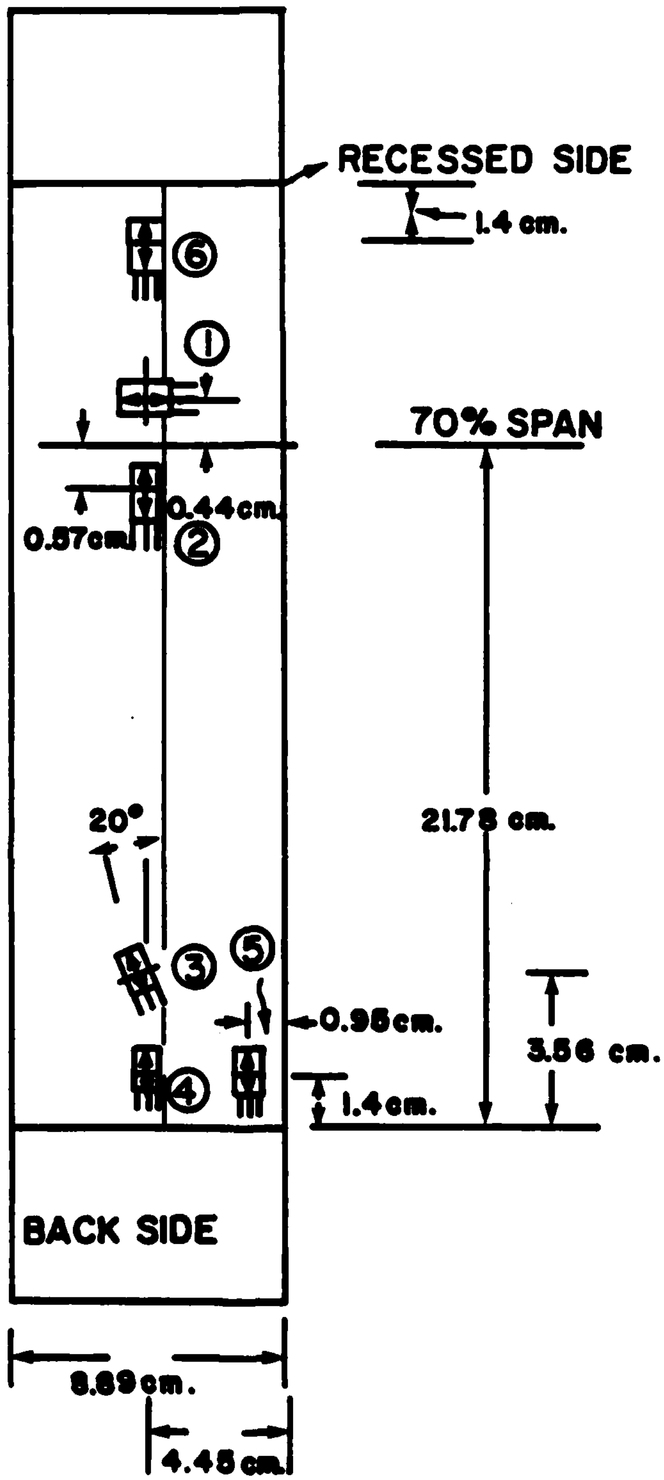


Figure 11A. Strain Gage Locations for Group 10 Structural Element Test Specimens.

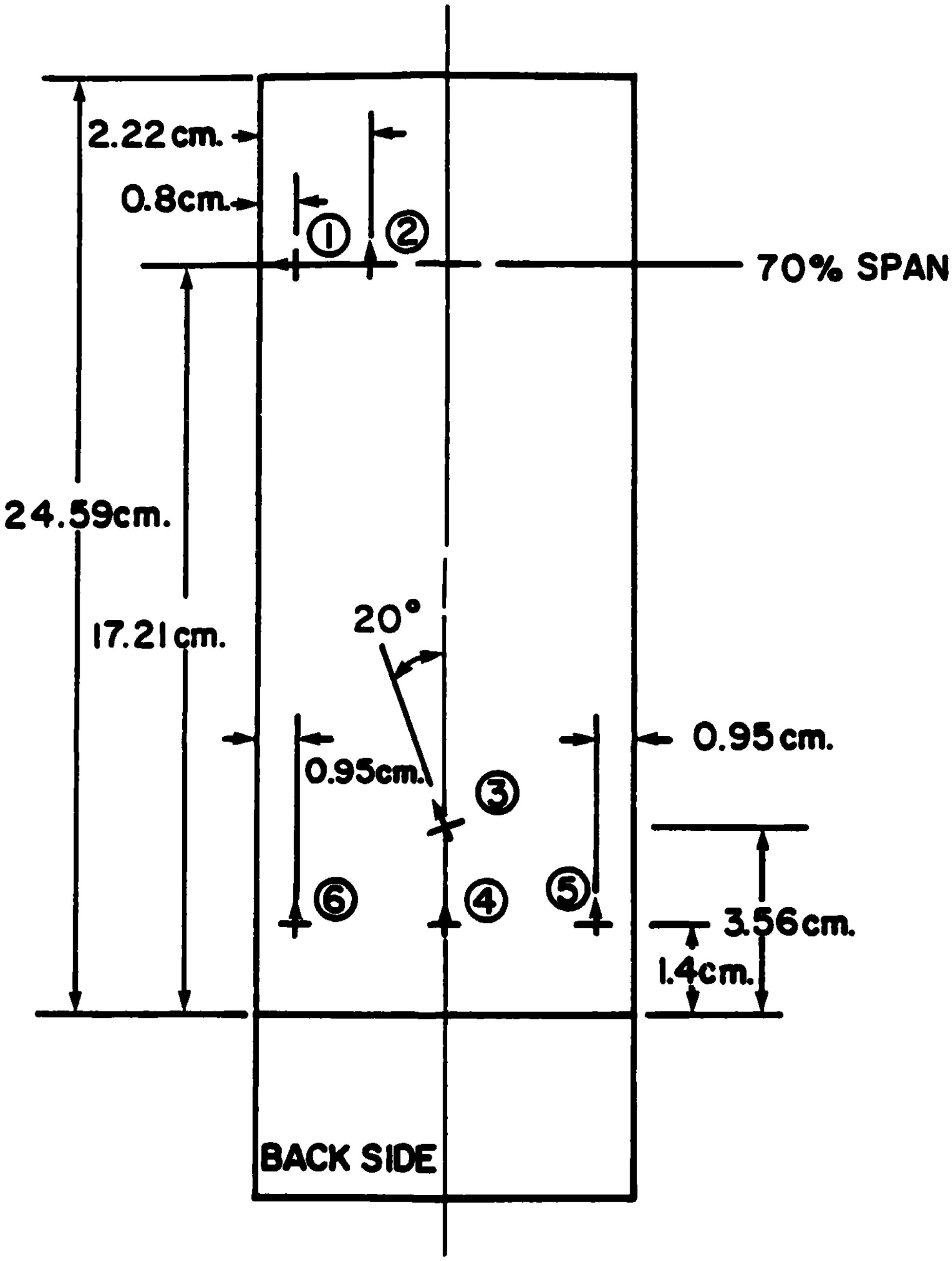


Figure 12A. Strain Gage Locations for Group 11, 12, and 13 Structural Element Test Specimens.

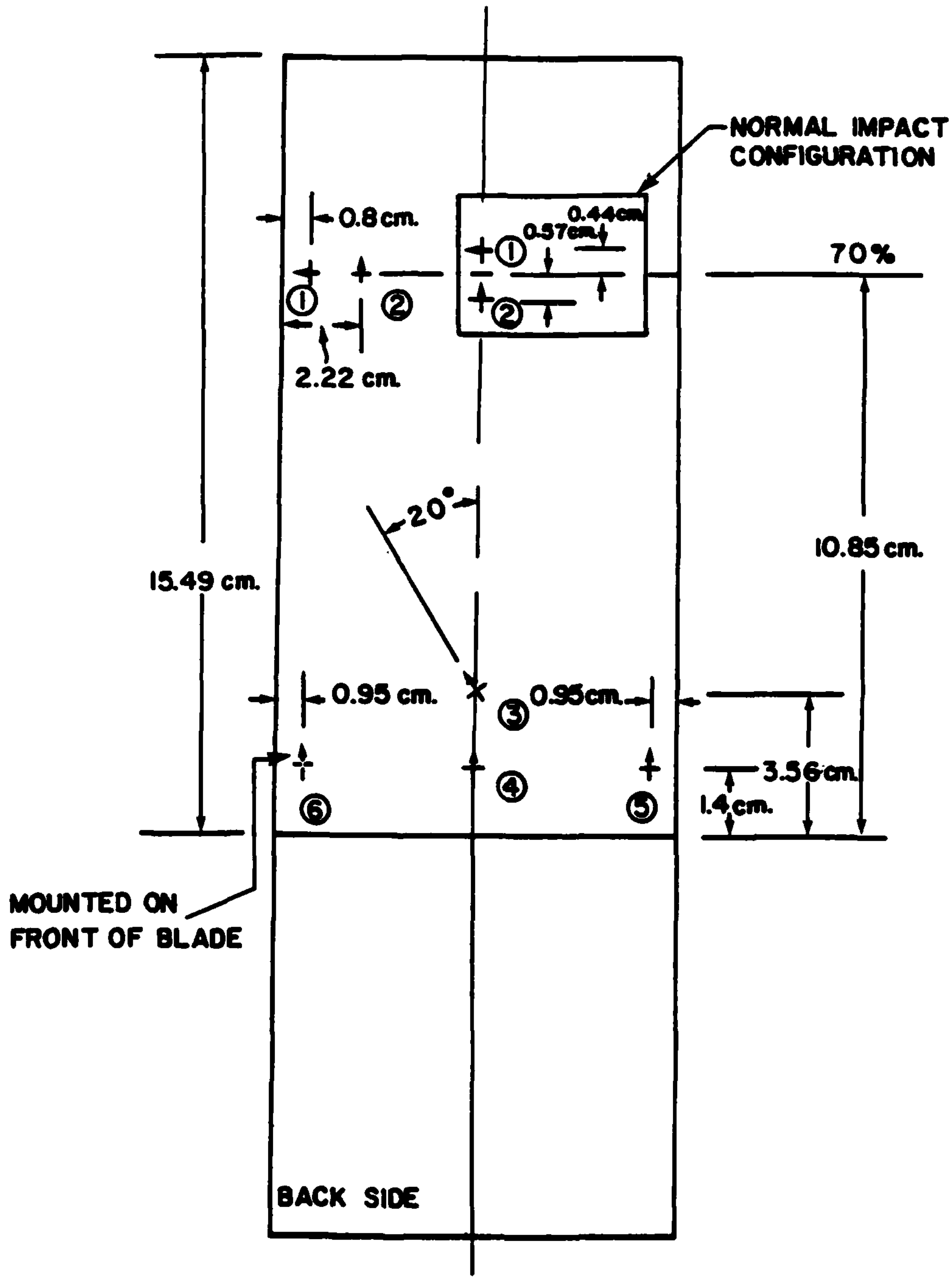


Figure 13A. Strain Gage Locations for Group 14 and 16 Structural Element Test Specimens.

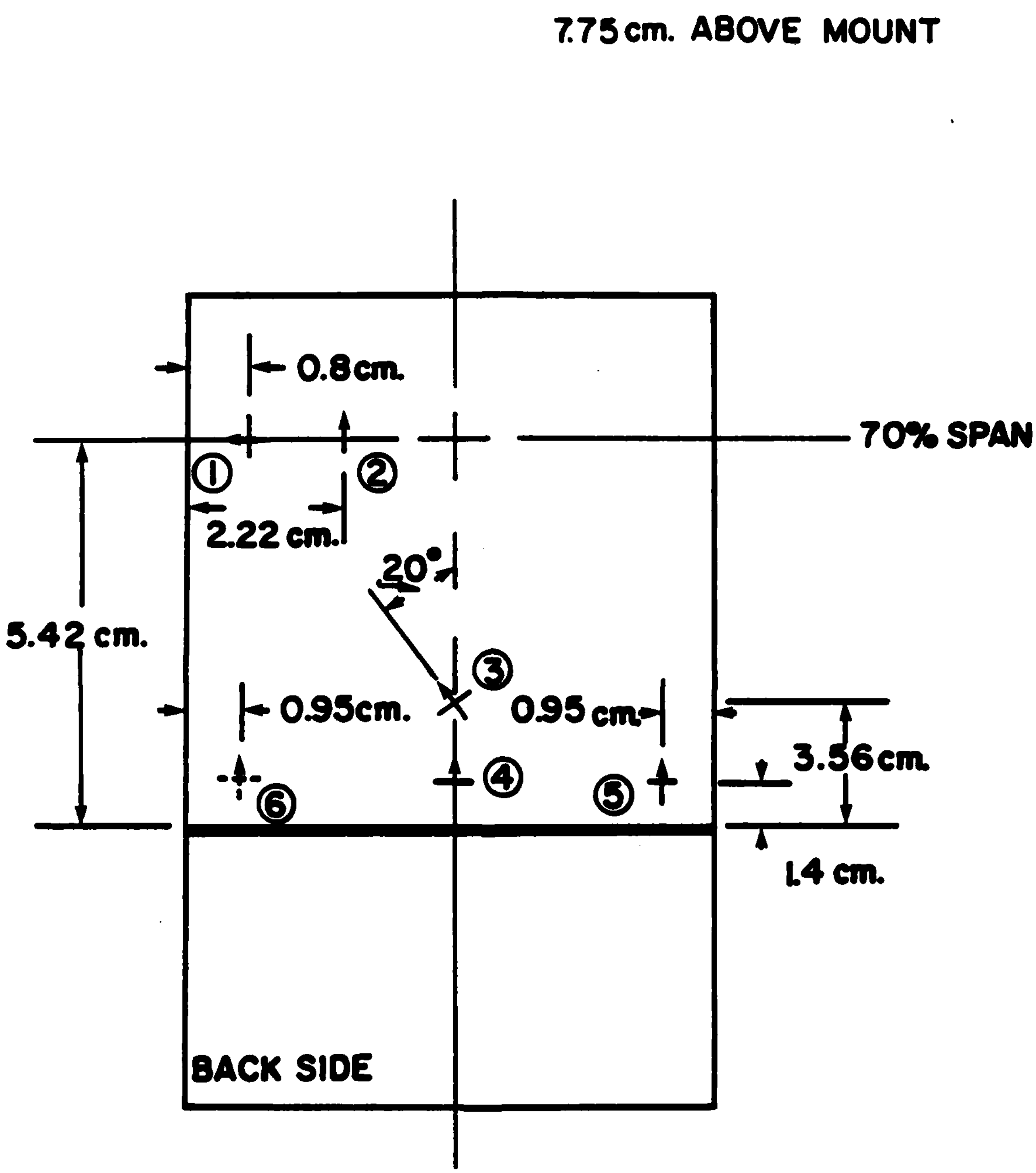


Figure 14A. Strain Gage Locations for Group 15 Structural Element Test Specimens.

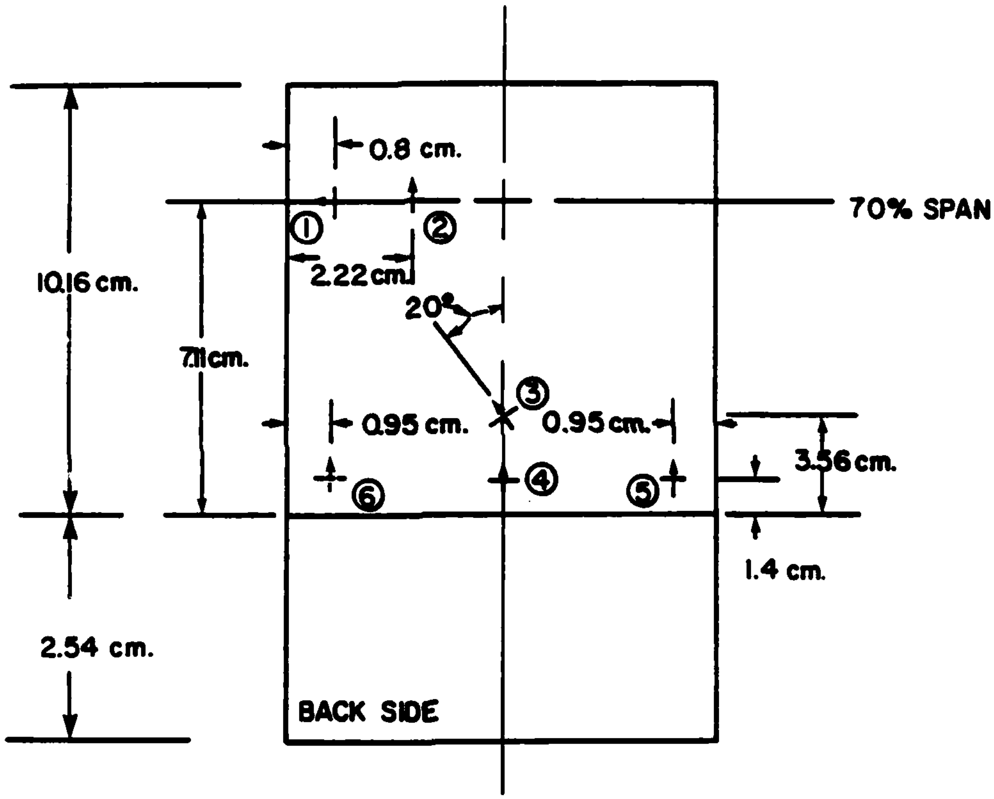


Figure 15A. Strain Gage Locations for Group 17 Structural Element Test Specimens.

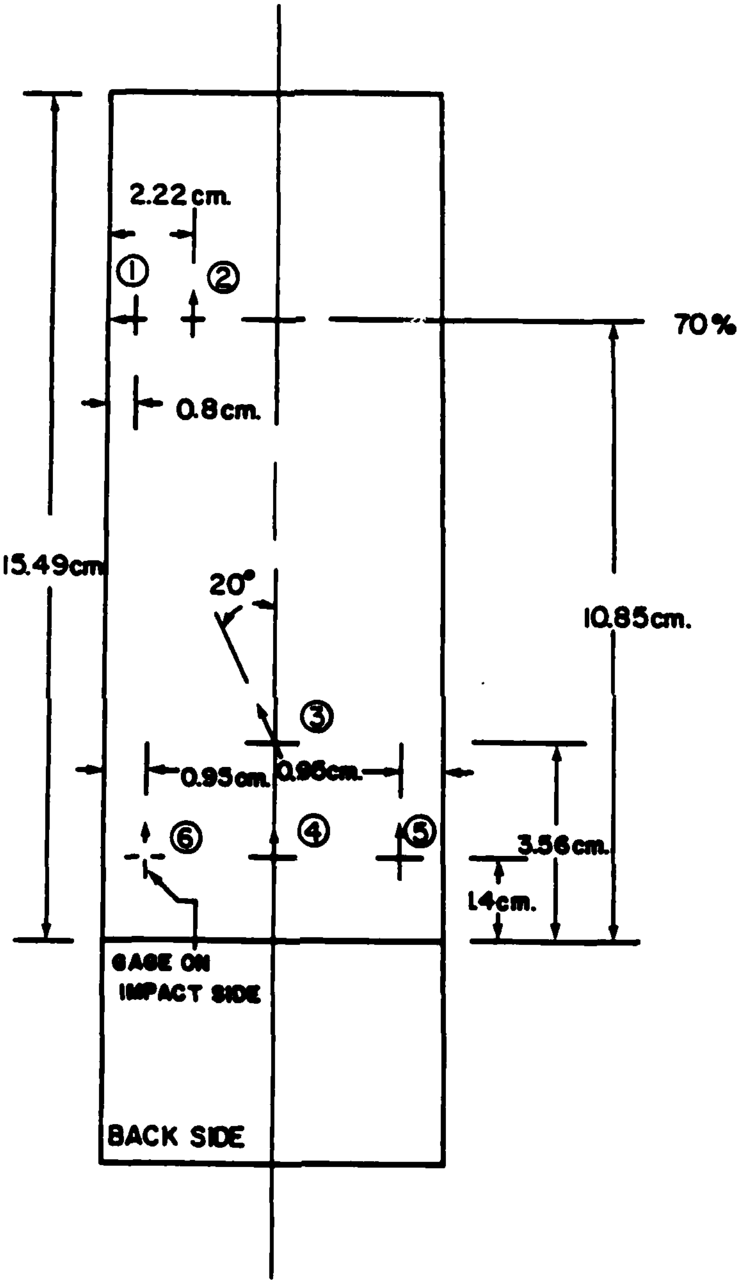


Figure 16A. Strain Gage Locations for Group 18 and 19 Structural Element Test Specimens.